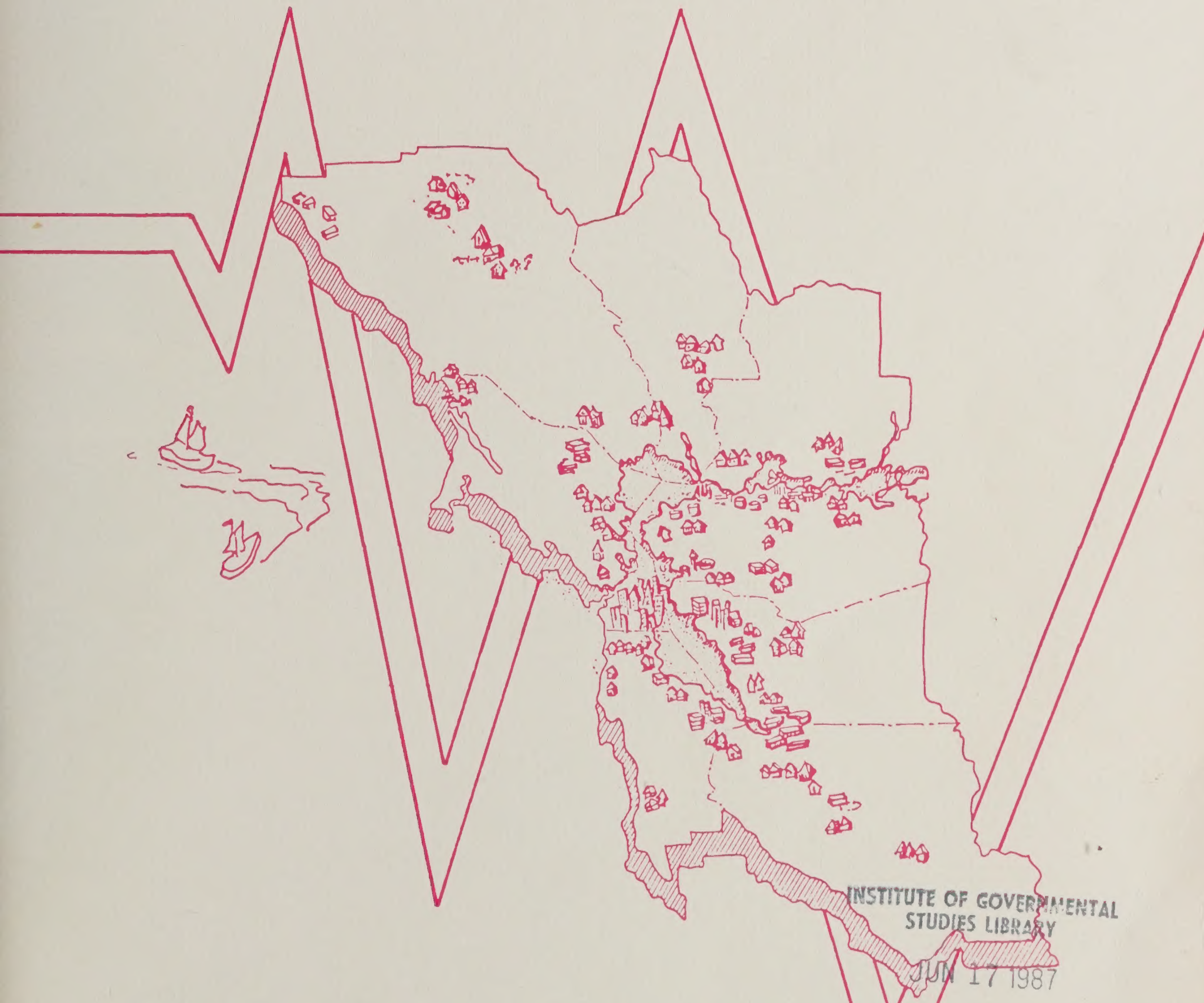
BUILDING STOCK AND EARTHQUAKE LOSSES -

THE SAN FRANCISCO BAY AREA EXAMPLE



MAY 1986

ASSOCIATION OF BAY AREA GOVERNMENTS

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INTRODUCTION

BACKGROUND

Since 1970, ABAG has been working to provide technical assistance on earthquake preparedness to local governments in the San Francisco Bay Area. Recent research has focused on earthquake hazard mapping, as well as public and private liability. The hazard mapping examined the problems of faulting, ground shaking, and ground failure--all problems with the ground itself. A logical extension of this work is to look at the potential concerns related to the buildings built on that ground and exposed to those geotechnical hazards. The project described in this report is intended to be such an examination.

ABAG developed, tested, and evaluated a variety of methods for producing a regional data file of building stock during 1984 and 1985. The project used the nine-county San Francisco Bay Area as a test case. The building stock information was evaluated based on its ability to improve the quality and usefulness of earthquake hazard identification and mitigation programs for that region. As an inventory of a region of 6,000 square miles and 5.5 million people, project staff could not look at every building, nor do the type of in-depth structural and geotechnical analyses necessary to predict the response of individual buildings in earthquakes of various sizes. Rather, generalized data were gathered on the type of construction of buildings in use in 1985 (referred to in this report as "building stock") for use in improving the quality of planning for future earthquakes expected in the San Francisco Bay Area.

This report is intended for two audiences:

- people interested in the project's techniques in order to collect building stock data in other metropolitan areas; and
- those interested in the project's findings related to building stock in the San Francisco Bay Area.

Two separate reports have not been prepared for two parallel reasons. Only through testing the techniques using a real metropolitan area could they be fully evaluated; only by examining the techniques used to gather the San Francisco Bay Area data can the limitations of those data be appreciated.

The work of the project was reviewed by a technical committee composed of local government personnel and researchers, of structural engineers and architects, as well as of planners and emergency response staff.

This report is not necessarily the most important product of the research. The actual building files can be ordered from ABAG for specific areas. In addition, ABAG has developed a workshop on how to conduct a hazardous building survey under a contract with BAREPP (The Bay Area Earthquake Preparedness Project).

THE ISSUE

Estimates of building stock by major structural type are key to predicting the extent of potential earthquake losses. More specifically, the building data and resulting loss estimates can be useful in a variety of ways, including the following examples.

(1) The most direct application is to provide insight on the level of local, State and Federal resources needed to respond to earthquake disasters.

(2) By enabling cities and counties to share data about how they are responding to mutual problems (for example, seismically suspicious masonry buildings), they can gain insight into ways to better resolve these difficulties.

(3) By providing a regional overview, cities and neighborhoods can be compared on a relatively equal basis and *pockets* of buildings likely to behave poorly in an earthquake can be identified. Such *pockets* may be noteworthy either due to the absolute <u>number</u> of building involved in the area, or due to the relative <u>percent</u> of buildings involved. Such *pockets* could become the focus of future efforts to mitigate the effects of earthquakes through improved emergency response and focused rehabilitation or reconstruction efforts.

(4) To the extent that the loss estimates for residential buildings can be converted to estimates of permanent and temporary homeless, cities and counties can prepare more effective Housing and Safety Elements for their General Plans, as well as make plans for providing emergency shelter.

(5) Since a metropolitan economy is large and interrelated, these data can be used to help predict the impact of hypothetical earthquakes on metropolitan, as well as the State and national economies.

Building stock data for an entire metropolitan area are particularly useful. By their very nature, major earthquakes affect large areas, impact areas interconnected in their infrastructure and economies, and require extensive intergovernmental coordination for emergency planning and response within (and outside) a metropolitan area. For example, a recurrence of the 1906 San Francisco earthquake would require response by all nine counties in the San Francisco Bay Area rather than just one city. Resources of one city would be overwhelmed and, by necessity, cities would rely on mutual aid agreements. Thus, inventories are most useful if they cover an entire metropolitan area; inventory techniques are most useful if they are designed to apply such regions.

However, metropolitan building and occupancy data are not easily obtained. Reasons for this shortage of useful data include:

- o the time and money required to prepare a comprehensive inventory;
- o the requirement that it be updated regularly to reflect new development and the reuse of land (through infill, rebuilding, and conversion);

- the need for a consistent framework within which to organize the huge amount of information and make it able to be transferred; and
- the availability of computer programs and a geographic information system for storage, analysis, and display of data.

Nevertheless, estimates of building stock are essential for meaningful emergency planning and response.

CONCLUSIONS

Surveying Building Stock

1. An accurate land use map of an area is essential in performing a building stock survey for a large metropolitan area. The map can help identify areas in which the variety of building stock present make *drive-though*, or *windshield* surveys, most beneficial. It also serves as an essential component in enabling cross-referencing to earthquake intensity exposure data. Although the LUDA land use maps available nationally from the U.S. Geological Survey are useful as a start in compiling a land use map, the maps need to be enlarged to a more detailed scale (a minimum of 1:24,000 or 1" = 2,000') to be useful in relation to building stock data.

2. Due to the size of metropolitan areas, a computer-based geographic information system is essential in cross-referencing among census, land use, intensity exposure, and building stock data. This project proved to be near the limit of resolution of the hectare-based grid cell system used. (One hectare is approximately 2 1/2 acres.) A grid cell system using a larger grid cell, such as 10 acres, would have been inadequate. A parcel based system may have been most useful.

3. Local building officials usually are very knowledgeable about the general building stock in their jurisdictions. However, data on absolute amount of building stock, such as number of buildings, number of dwelling units, or building square footage, are rarely available from them. Interview data are much less useful in extremely large cities, such as Oakland, San Jose and San Francisco in the Bay Area.

4. Great caution is required in using building survey data compiled for other purposes in a survey of this type. For example, surveys focusing on identifying seismically suspicious structures often omit data on amount of wood frame, light metal, steel frame, and reinforced masonry structures. Since the expected damage curves for these buildings vary, their relative share of the building stock is important.

5. Building stock can be extremely variable from one census tract to another. It is virtually impossible to gain accurate data on commercial/service building stock through sampling techniques.

6. Two reasonably accurate techniques for gathering building data in areas of a large variety of building stock are *drive-through*, or *windshield*, surveys and reviews of Sanborn maps. (Sanborn maps are maps made of city buildings by the Sanborn Map Company, largely for fire insurance purposes.) Both techniques proved quite accurate, although recent Sanborn maps are not available for all cities. Even though, drive-through surveys are much quicker in obtaining general building stock data, Sanborn map reviews can make compiling a list of addresses of suspicious masonry buildings, for example, quite simple.

7. Census data are useful in refining the residential building stock data, especially when data on type of construction of buildings of particular heights or ages are available but not the relative percentages of those types. In addition, census data can be used to estimate the number of dwelling units in a census tract and the mean value of those units. Caution is required in using the value data, however, because this information is estimated by the survey respondents.

8. Employment data (that is, data on people who work, not live, in a tract) can be used to estimate square footage of commercial/service and of industrial buildings in a census tract.

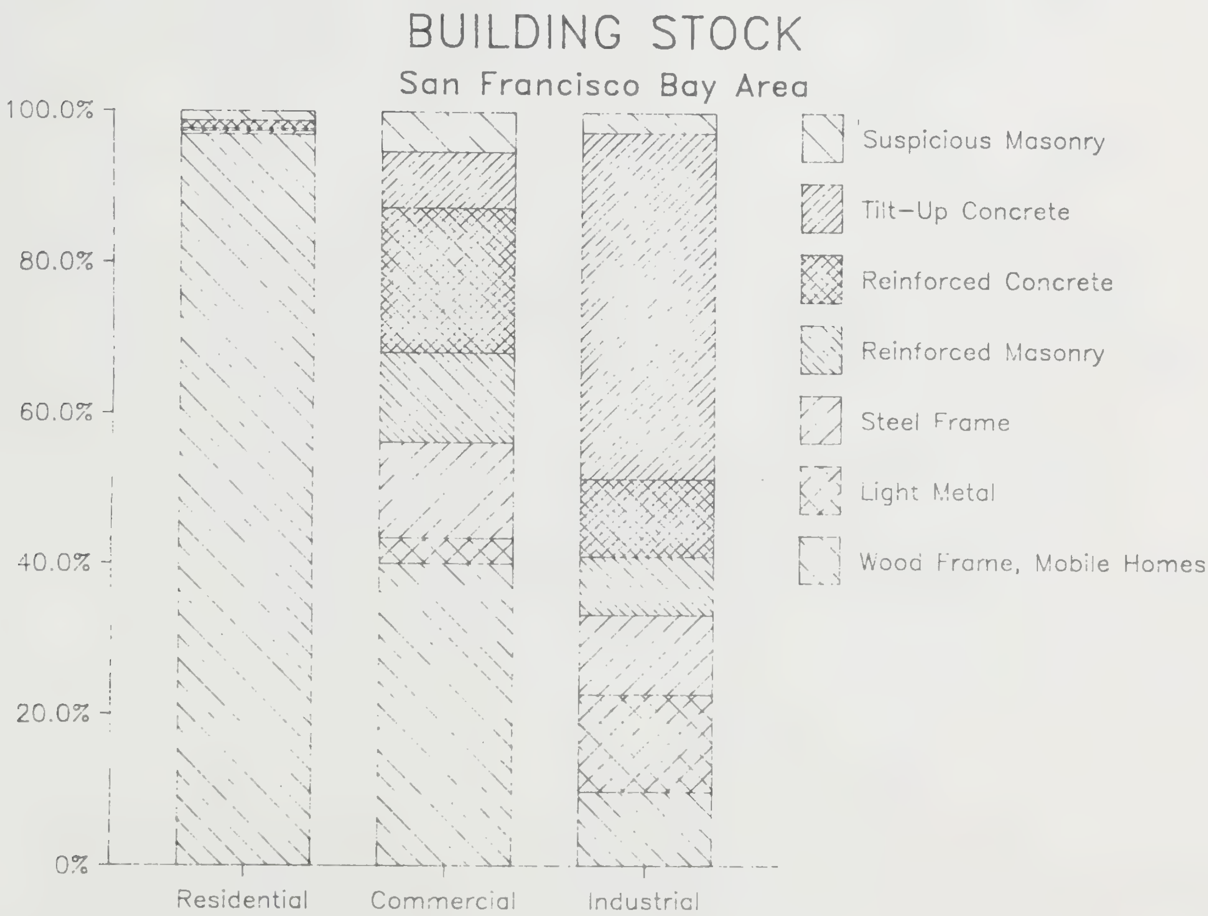
Bay Area Building Stock

Note: housing stock percentages are based on dwelling units, while commercial and industrial stock percentages are based on square feet.

1. Housing stock in the San Francisco Bay area is primarily in 1-3 story wood frame buildings. In fact, wood frame buildings of up to 4 stories account for almost 95% of the construction. Mobile homes, which are primarily light frame structures on temporary foundations, account for 2 1/2% of the units. Of the remaining 3% of dwellings, most are suspicious masonry or reinforced concrete, followed by steel frame and reinforced masonry. In the City of San Francisco, approximately 20-30,000 dwelling units may be in seismically suspicious masonry buildings, accounting for approximately 7 1/2% of its housing stock.

2. Commercial building stock is extremely varied. Although wood frame structures dominate smaller communities, this is balanced by more concrete and steel in larger cities. Regionwide, wood frame accounts for 40%, light metal 3%, steel frame 13%, reinforced masonry 12%, reinforced concrete 19%, tilt-up concrete 8%, and suspicious masonry 5%.

3. Industrial building stock is dominated by tilt-up concrete construction in the South Bay counties. In other areas the building stock is more mixed. Regionwide, wood frame accounts for 9%, light metal 13%, steel frame 11%, reinforced masonry 8%, concrete 10%, tilt-up concrete 46%, and suspicious masonry 3%.

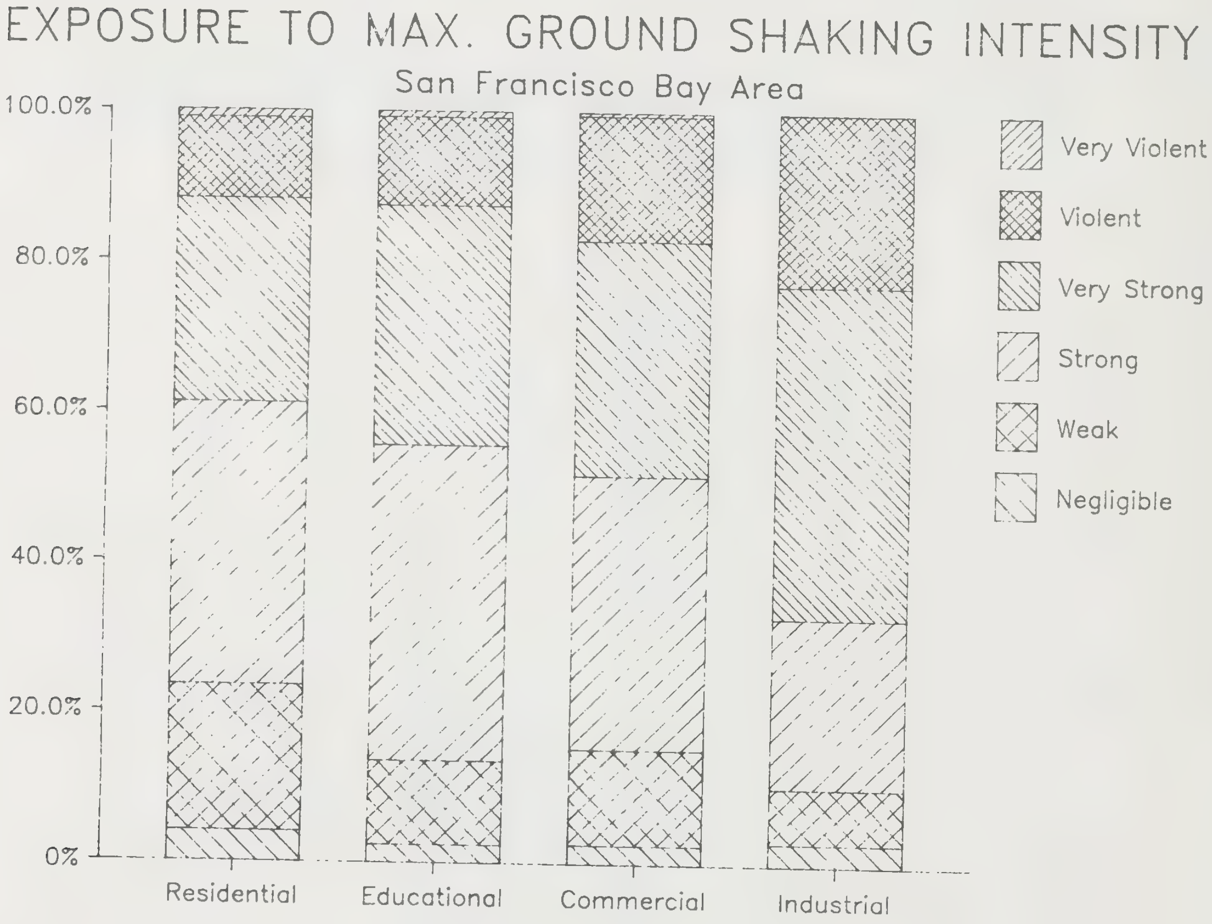


Potential Uses of Bay Area Building Data

1. Correlations between land use and maximum ground shaking exposure point out that industrial lands tend to be exposed to the strongest shaking, following by commercial, educational and residential uses, as illustrated below.

2. The survey data identified 4700 - 5400 under-reinforced masonry buildings, two-fifths in San Francisco. There are approximately 50 million square feet of commercial and 70 million square feet of industrial tilt-up concrete buildings. Although a third of the mobile homes in the Bay Area are in Santa Clara County, they account for the largest percentage of homes in Napa and Sonoma Counties.

3. Techniques to use the data to produce estimates of property damage, homeless caseloads, and casualties are available but are considered beyond the scope of this report.



REPORT ORGANIZATION

This report is organized into three major parts. PART A describes the relationships between buildings and earthquake response. The first section describes the general classes of buildings used in this analysis. The categories used in this project are based in large part on construction materials: wood frame, light metal, masonry (including the subcategories of seismically suspicious and reinforced masonry when available), and concrete and steel (including the subcategories of steel frame, reinforced concrete, and tilt-up concrete when available). In addition, height categories of low-rise (1-3 stories), mid-rise (4-6/7 stories), and high-rise (7/8+ stories and/or 75+ feet) are used in certain cases. Finally, the availability of age of construction, and its relationship to earthquake response, is discussed. In the second section, the performance of these types of buildings under earthquake loads are described using the relative performance of different types of construction and associated damage curves.

PART B describes the techniques to gather data on building stock that were used in this project. These include tying data to land use, interviewing local government staff, organizing previously gathered city data into a regional framework, conducting *windshield* or *drive-through* surveys, and gathering facility-specific data from the facility operators. The results for the San Francisco Bay Area are displayed by county for general residential, commercial, and industrial uses.

PART C describes the uses of building data to define earthquake hazards and their mitigation. Included are comparisons of land use to maximum intensity, examinations of unreinforced masonry, tilt-up concrete, and mobile home building problems, and discussions on estimating earthquake property losses, homeless caseloads, and casualties. Other potential uses also are mentioned.

THE NEXT STEPS

This report is the summary of a regional metropolitan effort. This work is intended not to replace, but rather to incorporate, community-level information. This report should provide those collecting such information with general data on their county and the region. As previously mentioned, census tract-based data are also available from ABAG. These data, together with Sanborn maps, windshield and walking surveys, examinations of building department and assessors' files, and structural evaluations of individual buildings, provide information useful in refining community inventories.

Additional work is also needed to make <u>useful</u> estimates of property losses, homeless caseloads, and casualties from future earthquakes. These building stock data are one piece of the complex analysis process leading to such estimates.

PART A--BUILDINGS AND EARTHQUAKE RESPONSE

I. CLASSIFICATION OF BUILDINGS

For purposes of seismic analysis, buildings can be identified by the nature of their structural system and that systems' components, their configuration (or shape), and their age.

The first method of classifying buildings is by their structural system. In simple terms, the complete system consists of vertical elements (such as columns and walls) and horizontal elements (such as floors, roofs, beams and girders). The methods by which these components are connected form an important part of the structural system. A further consideration is the foundation system that connects the structure to the earth. Finally, there are the nonstructural or architectural elements of a building. In consideration of the large variation in building stock of the nine Bay Area counties, use of these categories has been limited. The project has focused on identifying the principal vertical structural system.

In the building industry materials classifications are generally listed as follows-- light materials (including wood frame, mobile homes, and light metal), masonry such as brick and concrete block (either reinforced or non-reinforced), steel frame, and concrete (including cast-in-place and precast).

Configuration is a necessary category when considering building stock identification and the effects of seismic forces. Configuration deals with height, number of stories, proportion, size, shape and the location and arrangement of the major structural elements. This report categorizes configuration only by height.

Finally, it is important, where possible, to categorize buildings by their age. This information is useful for understanding changes due to advances in construction practice and the current status of building codes.

For purposes of this report, the building stock information has been subdivided into three major classification systems: (a) the material of the principal vertical system; (b) height; and (c) age (when available). Each will be described in more detail in this section.

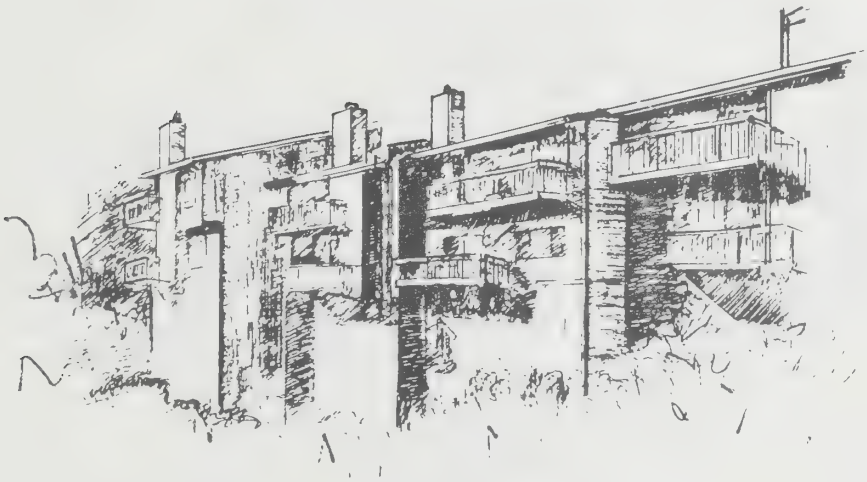
Before examining the following information one should have a basic understanding of building components and earthquake forces. A summary of key concepts is included in Appendix A of this report.

A. Materials of the Principal Vertical System

1. Wood Frame (WF)

Wood frame buildings are usually low (from 1 to 4 stories). Most tend to have wood stud bearing and non-bearing walls. For new construction, floors are generally plywood topped with the finish flooring. Plywood panels, called sheathing, are also nailed to the roof and serve as a base for wood shingles, composition roofing, or tiles. Exterior walls can be finished with wood panels, tongue and groove siding, shingles, stucco, or masonry veneer. Interior walls or partitions and ceilings can be finished with plaster, sheetrock, wallboard or tile. Foundations are generally concrete or masonry. However, the concrete or masonry may not be reinforced in older buildings. Very old structures are occasionally placed on the ground with only a mud sill foundation. Chimneys may be reinforced or unreinforced masonry, or prefabricated sheet metal, and either tied or not tied into the wood structure. The typical urban construction of 3 to 4 stories of light wood frame apartments supported on a fire-resistant construction of concrete, steel or masonry mixes two types of construction. The lower floor, usually used for parking, is generally open for ventilation. While heavy timber construction is not technically in this class, it is combined with light frame for this study.

Uses: Residential (single and multi-family housing), smaller commercial and hotels, and older industrial buildings.



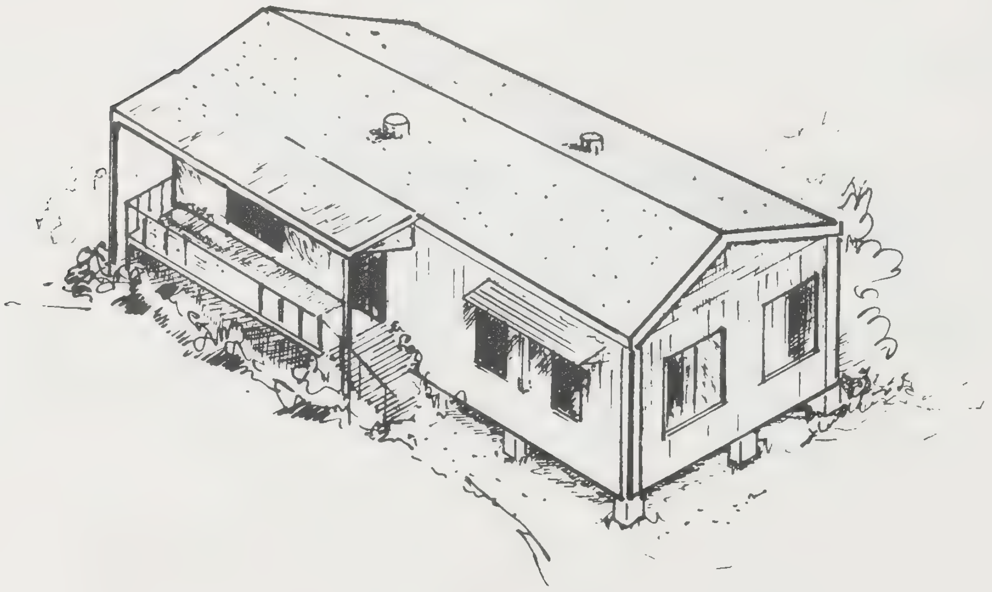
2. Mobile Homes (MH)

A mobile home is a factory-built dwelling either of light weight metal construction or a combination of wood frame structure erected on a steel frame chassis, with siding of wood, aluminum or fiberglass. Often, they are structurally linked to a second unit forming a double-wide coach. The units can be pulled on wheels to a site, leveled and supported in one of these ways.

o First, the coach can rest on the ground with only small metal devices called screwjack levels between it and the soil. The screwjack level consists of a metal triangle shaped base, like a tripod, with a screw and plate to connect it to the coach.

o Second, the coach can be supported above ground by resting on piers generally spaced about 6 feet apart. The undercarriage is leveled between these piers with screwjack levelers or wood blocks (called shims). The piers are made of concrete or steel or unreinforced concrete or cinderblock. These piers can rest on either a concrete slab or on treated wood that sits directly on the ground.

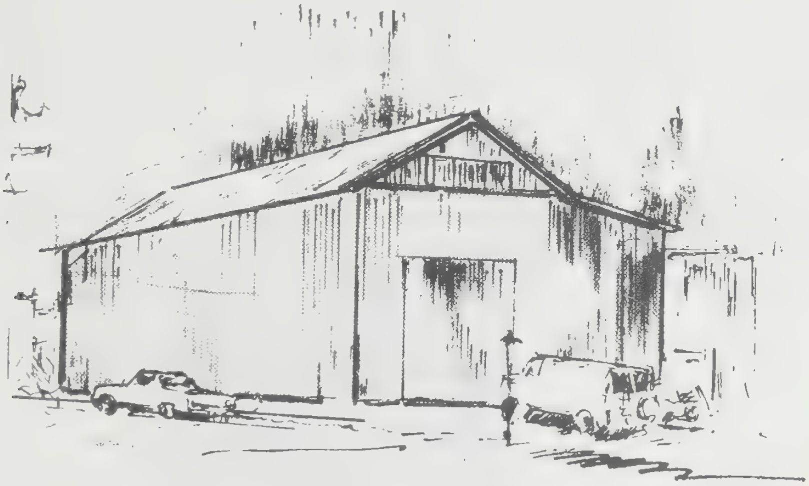
o Finally, the coach can be supported by reinforced concrete foundation units at the cormers coupled with tie down connections to its frame.



3. Light Metal (LM)

Light metal structures contain light metal stud walls with metal sheathing or a stucco finish. Floors tend to be concrete or plywood on steel joists. Interior walls and ceilings tend to be sheetrock. Roofing can be of a variety of materials, including corrugated metal.

Uses: gasoline service stations, warehouses, industrial buildings, agricultural buildings and small shops

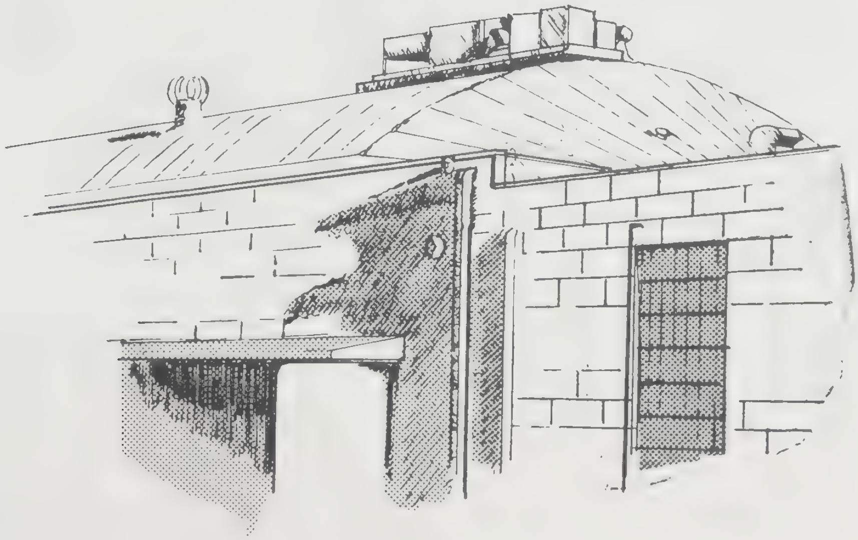


4. Masonry

a. Reinforced Masonry (RM)

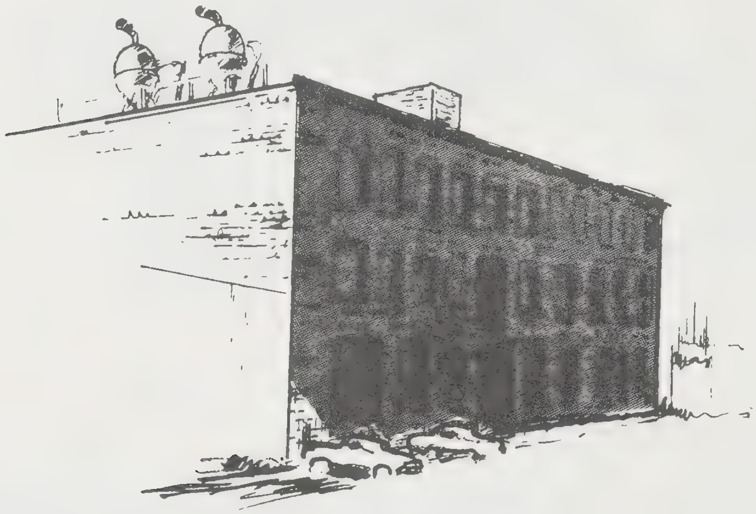
Reinforced masonry construction has as its primary material concrete block or brick. The structural system generally consists of masonry bearing and shear walls, with wood floors and roofs, although metal deck floors and roofs also are used. Inside partitions may be wood or light metal stud walls.

These buildings are limited to 4 or 5 stories in height, except for some relatively recent construction of up to 16 stories in height with concrete floors and roofs. There are several reinforced masonry buildings of 8 or more stories in the Bay Area.



b. Seismically Suspicious (SS)

Although usually adobe, stone, or brick, concrete block structures with either no grouting, no steel reinforcing, or both are in existence. Floors, roofs and internal partitions in these bearing wall buildings are usually of wood. So-called "seismically suspicious" masonry was usually constructed in an era when reinforcing was generally not used, or when anchorage to floors and roof were missing, or when low strength lime mortar was used. Construction of reinforced masonry became common sometime between 1933 and 1955, depending on local codes and quality of code enforcement. These buildings are only suspicious. Many older masonry buildings performed excellently in strong earthquakes. They require detailed review to verify their adequacy.



c. Masonry (MA)

Categorization applied to masonry buildings when the level of reinforcing was unknown. In more detailed studies, they could be assigned to either of the two masonry categories provided above. Most of these buildings are of concrete block built in the 1940s and 1950s.

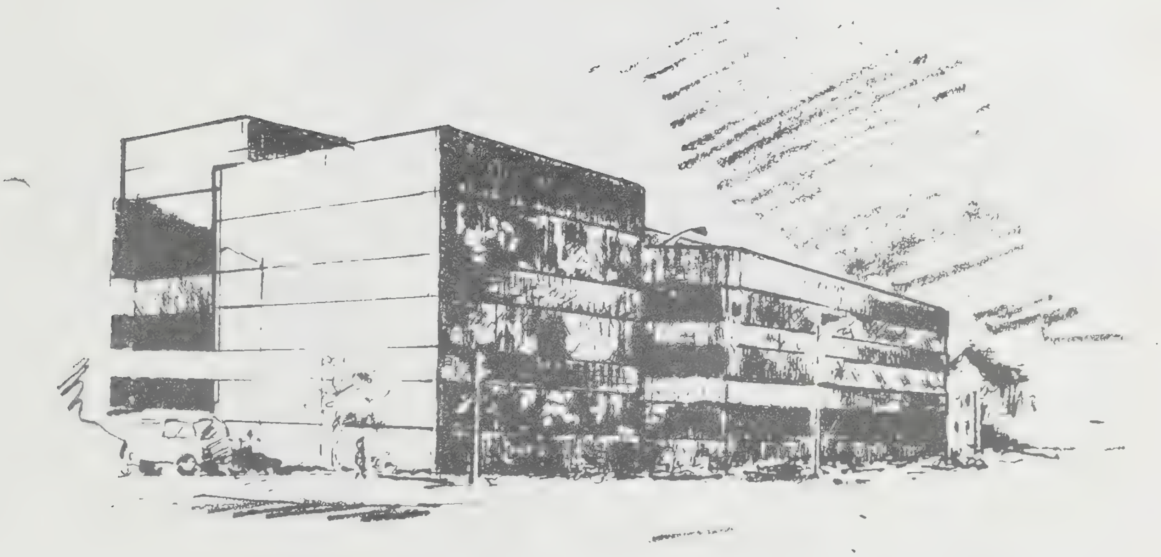
Uses: Commercial, housing and industrial

5. Concrete and Steel

a. Steel Frame (SF)

Steel beams and columns with either simple, semiriged or moment connections are commonly used with concrete over metal deck, or, commonly in older buildings, concrete slabs for floor and roof. The steel frame may be combined with masonry walls (unreinforced in older buildings), cast-in-place concrete walls or light-weight pre-cast concrete curtain walls. Interior elevator, stair and duct shafts may be part of the structural system, or of nonstructural light-weight construction. Modern mid- and high-rise office buildings use a moment-resisting frame and concrete over steel decking for floors. In earlier construction, all columns were designed to be moment-resisting. More recent construction may use this type of connection only in the perimeter frame or in a few of the frames.

Low-rise buildings may have wood floors and roofs. In fact, steel framing may be a principal component of so-called "mixed construction", which may have a steel frame, reinforced masonry shear walls, wood floors, and light weight curtain walls, internal walls and partitions.



b. Reinforced Concrete (RC)

Concrete buildings are constructed in a variety of ways. Cast-in-place concrete frame buildings with steel reinforcing usually have concrete beams and columns. These may be reinforced to act as a ductile structure or may be non-ductile. Uniform Building Code requirements were revised in the early 1970s to require ductility. This change is usually accomplished through the use of limited longitudinal steel (that is, steel running lengthwise in the columns), more overlaps in that steel, more steel in the joints between beams and columns, and more confining steel (usually in a spiral pattern around the longitudinal steel rather than as simple circles or squares enclosing it).

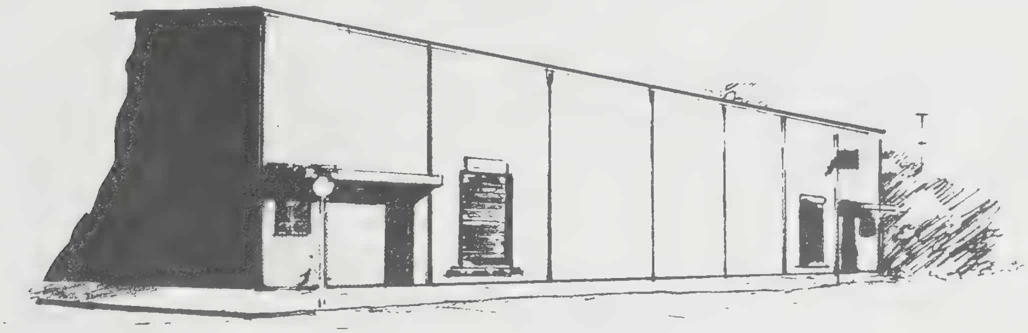
The building may have reinforced cast-in-place concrete walls, nonstructural cladding, or curtain walls.

In these structures, the floors may be steel decking or concrete slabs. If concrete, they may also be precast.

Older concrete buildings often are cast-in-place bearing wall design. The marks made by the wood form boards often are quite visible. However, relatively old concrete frame structures also exist in the Bay Area.

c. Tilt-up Concrete (TU)

Tilt-up concrete is a construction method using walls of reinforced concrete that are cast flat and tilted up into place. These wall elements may be interconnected with pilasters, or may be separated. The detailing of the anchors and the diaphragm, and the interconnections of the walls can vary widely, yet this detailing has a major effect on earthquake performance. Floors may be timber, metal decking or concrete (that is generally precast). Internal columns and beams may be of steel, wood, or precast concrete. The roof is often wood.



d. Concrete and Steel (CS)

This category of construction was used in this project when a building (usually small) of concrete or steel could not be quickly classified as either having a concrete or steel frame without unwarranted effort.

Uses: All types of commercial, service, office, and industrial uses; only multi-family residential; steel frame buildings are the most common office building being constructed in the 1980s

B. Height

The second category is one element of configuration--the height of the building. The categories are:

- o low - 1 to 3 stories
- o mid - 4 to 6/7 stories, or up to 75 feet
- o high - higher than 6/7 stories or greater than 75 feet, depending on the source of the height data

Basements and penthouses were not included. In classifying building stock, the abbreviations L, M, and H were used, corresponding to the above categories.

C. Age, Construction and Earthquakes

The age of construction can give certain clues as to how various building types were detailed and the quality of materials. Therefore, age data, provided in a general sense as decade of construction, was collected when easily available as a third category of construction classification.

The following discussion on the development of building codes is intended to provide a novice with a sense of the importance of these changes. Note that significant changes in construction codes and practice are usually triggered by earthquakes.

Earthquake knowledge affecting building codes is only one hundred years old. Although records of varying degree exist about ground motion activity reaching back into ancient times, it was not until the 1880s that Japanese, English and American scientists got together to study the scientific and engineering problems of earthquakes. Recommendations for the construction of buildings were published in this first collection of documents about modern seismology. Structural engineers began to increase their knowledge by studying rigidity in buildings and forces due to earthquakes after those of Mino-Owari, Japan (1881), San Francisco, USA (1906) and Tokyo, Japan (1923).

The Seismological Society of America (organized in 1910 as a result of the 1906 earthquake) has been a forum for engineering study and research. The 1925 Santa Barbara earthquake caused the Commonwealth Club of California to appoint a "Committee of 100" to study the earthquake problem. The California State Chamber of Commerce initiated a building code to reduce earthquake hazard in 1928. Palo Alto was the first of fifteen cities in California to legislate mandatory earthquake building requirements after the 1925 Santa Barbara earthquake and before the 1933 Long Beach earthquake. The earthquake reporting program was shifted form the Weather Bureau to the U.S. Coast and Geodetic Survey in 1925. USC&GS designed strong motion instruments and located a few in time to obtain a recording of the 1933 earthquake. In 1927, the Pacific Coast Building Officials (now ICBO) was organized and published the first Uniform Building Code. The earthquake provisions were in an appendix until 1961 when they were moved into the main body of the code. Much of this was due to studies in San Francisco on lateral forces of earthquakes and wind. Statewide, structural engineers developed recommendations for earthquake design with a commentary, now known as the SEAOC Blue Book. This text has been consistently updated and revised as new information became available. The Long Beach 1933 earthquake was spectacular in the damage to schools and public buildings, and, as a result the Field Act and Riley Act were passed by the legislature. The Field Act required that the State Architect develop regulations to improve the safety of public schools in earthquakes and monitor the construction. The need to keep hospitals functioning and prevent widespread fire after serious earthquakes as well as damage to transportation systems and facilities are essential considerations in earthquake country. Legislation building some of these concerns into design followed the 1971 San Fernando earthquake.

Each major earthquake that occurs teaches engineers and architects new lessons about building type performance. For example, the need for reinforced concrete to be more ductile (or tougher), the anchoring and connecting of curtain (non-bearing) walls, and tilt-up concrete construction performance have been and will be the subject of revisions to the codes concerning earthquake response because of extensive earthquake damage. Further reviews of building will result in stronger new buildings.

Hazards due to falling nonstructural elements from building exteriors and within interiors are leading to significant concern for anchoring methods and applications of safety features. Parapets, cornices, facade systems, tiles, precast concrete, and unreinforced masonry with weak mortar can be dangerous elements when they become dislodged from the major structure.

Generally these hazards are due to ground motion, not the hazards that result from ground failure such as landslides, ground settlement, flooding or tearing apart due to building on a fault.

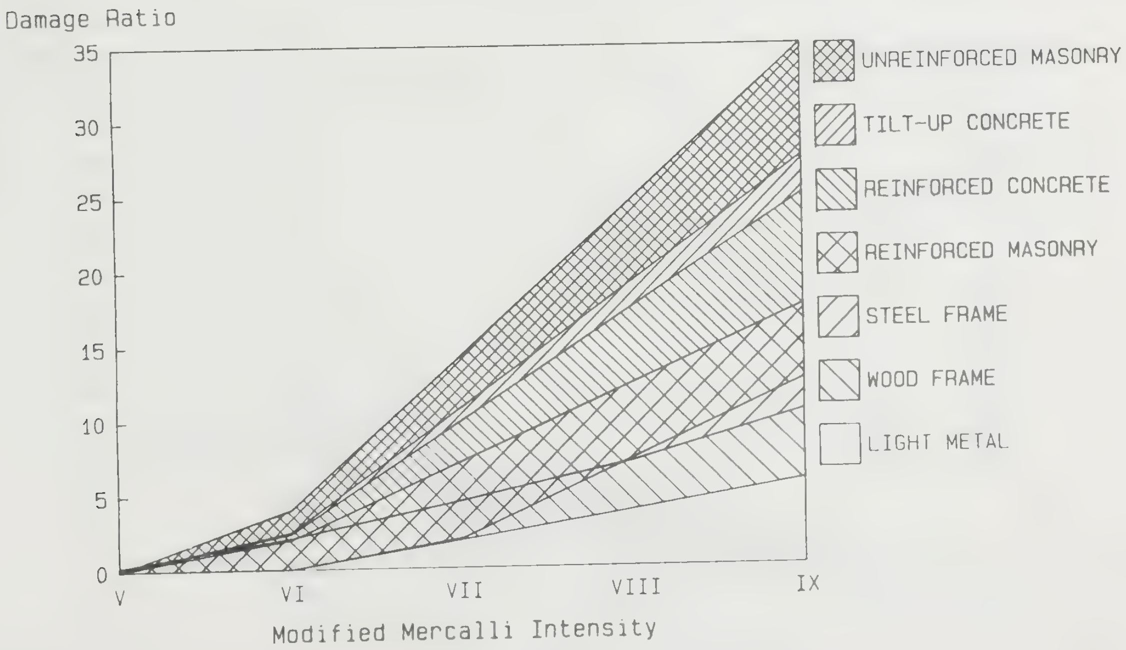
II. PERFORMANCE OF BUILDINGS DURING EARTHQUAKES

Experience from past earthquakes can be used to estimate the damage that different types of buildings could experience when subjected to various intensities of ground shaking. Once detailed damage statistics are collected for particular earthquakes, the data need to be generalized to apply to future hypothetical events. This generalized information can be supplied as an approximate average damage factor for each intensity level. This factor is defined as the cost of repairing a building divided by the cost of replacing that building. It can be viewed as a percentage loss and is expressed in percentages. Curves of this percentage loss vs. ground shaking intensity can provide a relatively simple means of gauging the relative performance of buildings during earthquakes.

For purposes of this discussion, curves prepared by Algermissen, Steinbrugge and their associates have been used. (See Rinehart and others, 1976, and Algermissen and Steinbrugge, 1978.) Subjective information is also becoming available from a research project performed by the Applied Technology Council (ATC-13, draft, 1985). This project used a Delphi-type questionnaire process to compile damage information. The advantages and disadvantages of each set of data for selected applications are described in Appendix C.

The relative performance of structures can be related to the material of their principal structural system and the general means of construction. The graph below illustrates the ranking of the general building types used by this project. Light metal and wood-frame construction are the least vulnerable to damage, followed by steel frame, reinforced masonry and concrete. Tilt-up concrete and unreinforced masonry buildings that are poorly tied together tend to be among the most vulnerable. Although this chart looks fairly simple, there is actually a great deal of variation in the curve alignment, depending in large part on the extent to which earthquake damage control features were included in the structural design, as shown on the following pages.

EXPECTED DAMAGE
TO SELECTED BUILDING TYPES



A. Light Frame Buildings

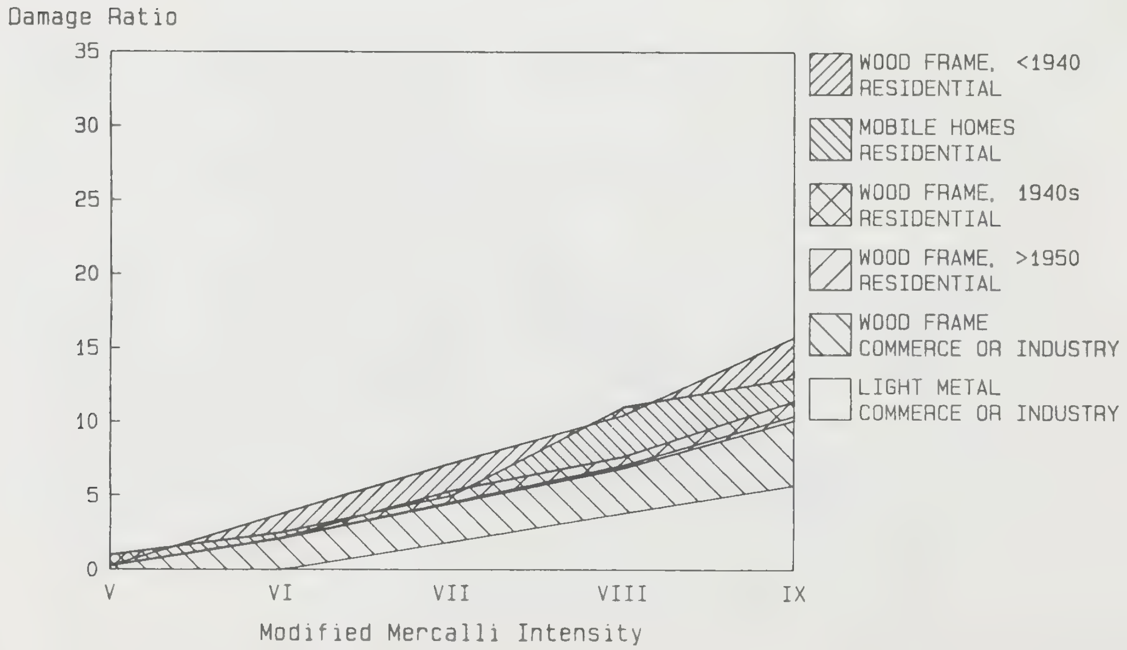
During earthquakes, light frame structures generally perform well due to the flexible nature of the materials and the sturdy and redundant system of elements and connection, frequency of nailing and general framing.

Buildings constructed of light construction materials for residential units include three age categories of wood frame dwellings, as well as mobile home units. Older wood frame dwellings tend to suffer greater damage in earthquakes than newer units due to inadequate or unreinforced foundations, lack of bolting of the homes to their foundations, and unreinforced masonry veneers or chimneys. Although masonry veneer, plaster and sheet rock may crack and pull away, total collapse of the entire structure is rare. Mobile home units tend to experience problems with inadequate foundations and with inadequate connections between the foundations and the units.

Split level dwellings, with a garage under second-story bedrooms, have a history of problems. In the wood-frame over parking situation, the parking level will perform in accordance with its design--ductile or non-ductile concrete, steel frame, reinforced or unreinforced masonry. The wood portion of the construction will perform similarly to other wood dwellings except that the base shaking will be amplified. The performance of the parking structure in past earthquakes has not been good. Any full or partial collapse of this underlying structure will result in damage similar to ground failure under more typical wood buildings.

Buildings constructed of light materials that are commercial and industrial can be of wood or light metal. The wood curve shown in the diagram below is different from that for wood dwellings because it excludes chimney damage. Siding can be bent, cracked, or loosened. Cracks and other bending tends to occur most around large openings, often causing windows to shatter. In light metal structures, the rod or light tension bracing is often stretched, broken or pulled out.

EXPECTED DAMAGE
TO LIGHT FRAME BUILDINGS

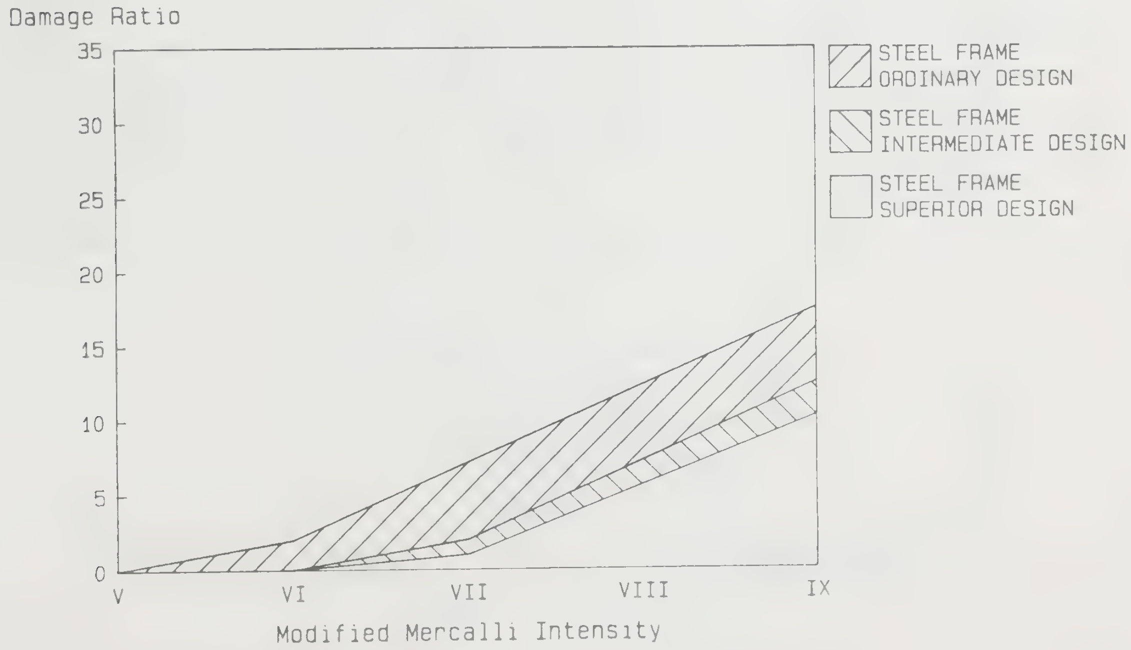


B. Steel-Frame Buildings

The ABAG category of steel frame buildings includes a vary large variety of structures. The category includes, for example, steel frame structures with unreinforced masonry shear walls and infill walls. It includes modern office buildings with concrete floors (horizontal elements) and precast lightweight concrete curtain walls. It also includes short buildings of 1-6 stories with wood floors and partitions. In general, the buildings are quite flexible with associated lack of collapse but major nonstructural damage. Thus, functioning of elevators, plumbing and equipment is likely to be disrupted and exit doors amy be jammed.

Many commonly used precast curtain-wall connections have not been proven adequate in an actual strong earthquake. Recent research on these connections indicated that there may be trouble ahead. In the case of steel industrial buildings, bracing may stretch, fail or buckle, but structural failure is rare. Damage to pipe connections and other nonstructural systems is common. Modern office buildings with perimeter moment-resisting frames and concrete floor slabs had not collapsed in an earthquake until Mexico City. In the case of braced-frame structures, diagonal bracing typically buckles, stretches, or pulls apart at the connections. After the braces buckle, deformations of the structure could become large with consequent greater damage. Steel frame structures with concrete or masonry shear walls (to form a dual bracing system) have had the best experience of any type of large structure. The stiffness of the walls limits the motion and consequent drift damage. Walls will crack but the repair costs are low. Steel frame structures with precast shear walls are not expected to perform well in earthquakes, but none have been tested. The performance of steel frame structures with an incomplete frame, but an internal core (usually of concrete), depends on the quality and strength of that core. Such construction is prohibited in California in buildings over 160 feet. Steel frame construction mixed with masonry walls and wood floors has a large range of performance experience; it can perform well, or it can behave poorly. Finally, masonry infill walls may come loose and fall to the ground.

EXPECTED DAMAGE
TO STEEL FRAME BUILDINGS

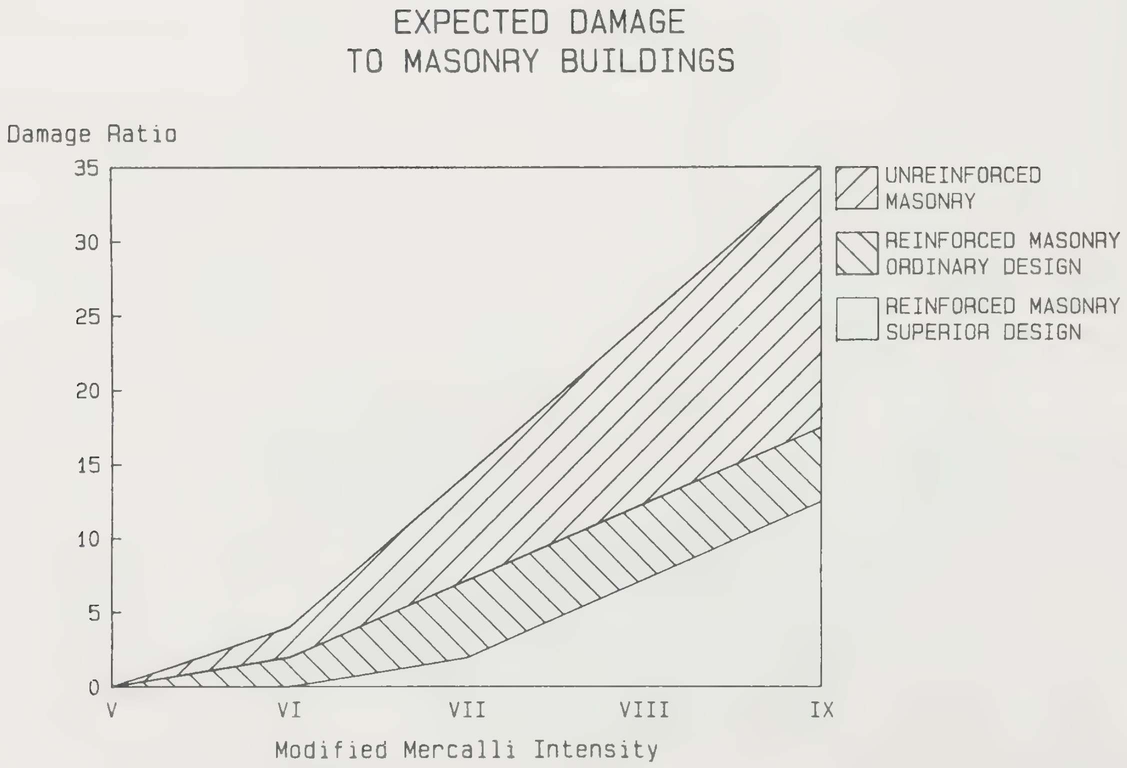


C. Masonry Buildings

Masonry buildings that are reinforced are subject to less damage than are unreinforced masonry structures. Two additional factors can impact reinforced masonry building performance. Several reinforced masonry residential buildings of 8 or more stories exist in the Bay Area. These tall reinforced masonry buildings have never been subjected to a major earthquake. Therefore, there is no data on which to base estimates of future performance. The extent of problems is unknown. Secondly, concrete block and masonry buildings may have some reinforcing yet not be of modern reinforced masonry construction. The damage curve for these structures is somewhere between the two major damage curves.

Potentially hazardous unreinforced masonry buildings are only suspicious; many older masonry buildings have performed excellently in strong earthquakes due to quality of work, relatively small openings and adequate wall anchors to the floor diaphragms. They also are not automatically a collapse hazard. When the external walls fail, the internal wood partitions may be adequate to support the floors for long enough for most occupants to leave the building.

The range of damage curves for all masonry buildings is shown is the chart below.



D. Concrete Buildings

The range of expected performance of concrete buildings varies widely due in part to the large variety of applications. However, in all concrete buildings, nonstructural damage to elevators and plumbing, as well as to contents, may occur.

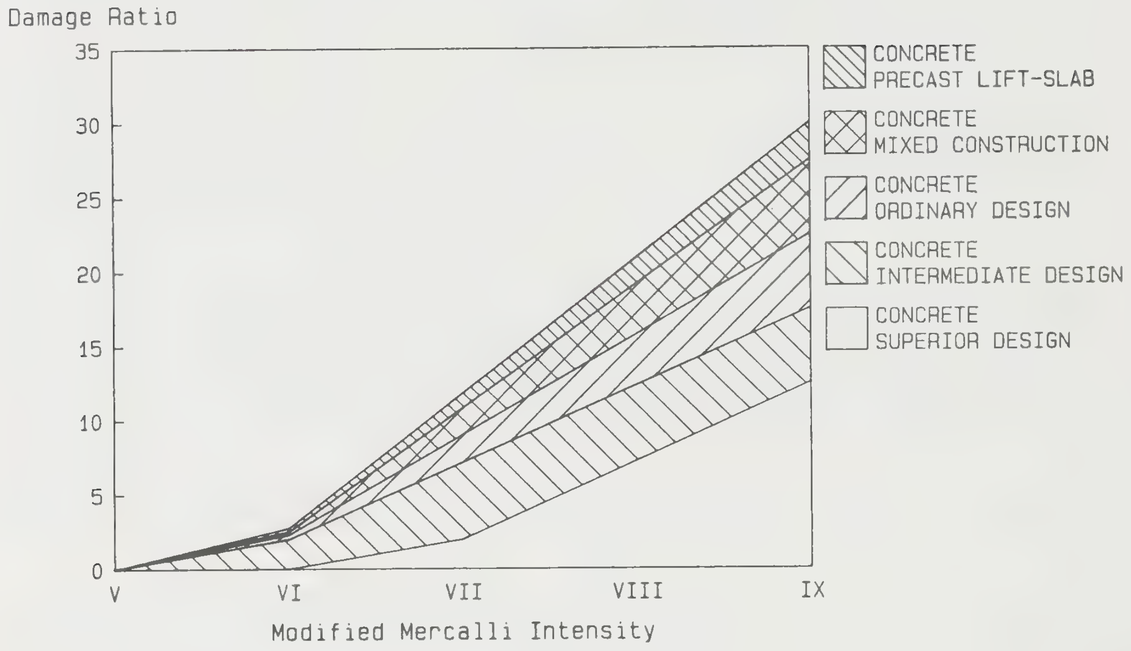
Older concrete buildings with cast-in-place concrete walls have performed very well, even though they may have not been designed to resist earthquakes. As compared to that, older concrete moment frames, where reinforcing was not detailed nor installed to give ductile performance, and which used curtain walls rather than cast-in-place walls, have performed poorly in every major earthquake since 1964. The Mexico City earthquake is no exception. San Francisco's code was changed in 1968. The Uniform Building Code was changed in 1973 following the San Fernando earthquake. The Bay Area has large numbers of these buildings, particularly in San Francisco, Oakland and San Jose. This building type also includes parking garages with relatively heavy concrete roof systems ostensibly braced by slender non-ductile concrete columns. This type of structure is subject to collapse in the event of an earthquake.

Lift slab construction has been subjected to few earthquakes. However, its few experiences have been unfortunate. But with proper detailing and redundancy, this type of construction could perform well.

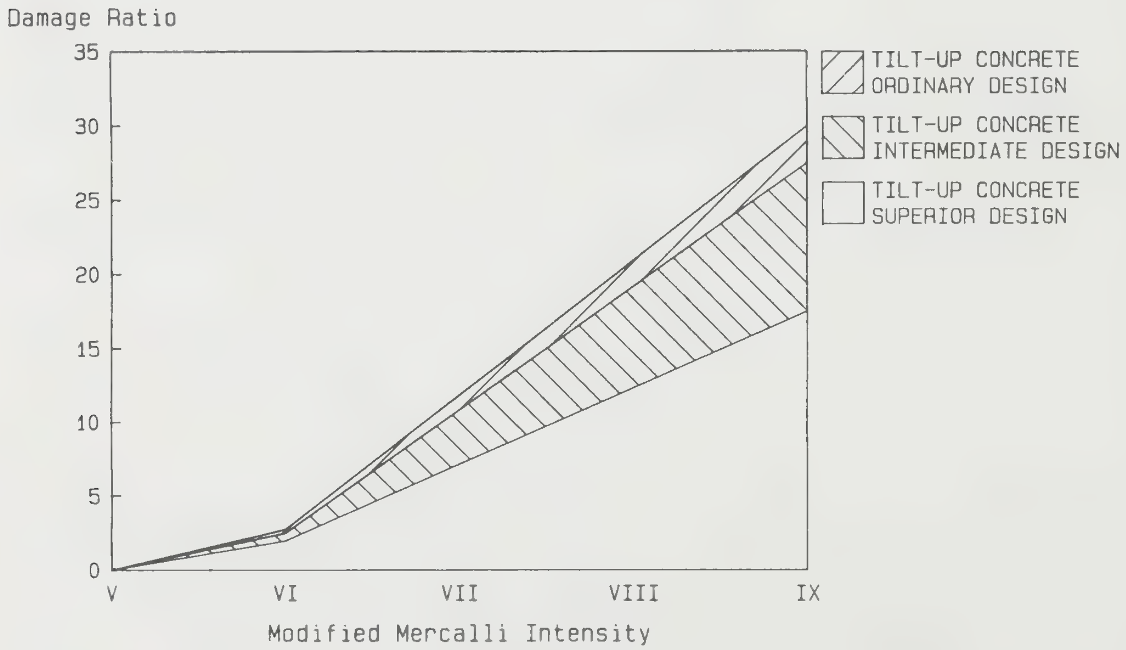
The performance of tilt-up concrete walled buildings also varies greatly with concept and detailing, and will vary from very good to exceptionally bad. Many pre-1973 tilt-up buildings were constructed with poor anchorage of the roof to the walls. Diaphragms can separate from walls or pull apart causing very serious damage. These buildings also can exhibit major nonstructural damage. The performance of tilt-up concrete structures built after 1973 is not expected to be better. A recent report of the Committee on Hazardous Buildings of the Seismic Safety Commission notes: "Wall-diaphragm connections and diaphragm details have improved since 1973,...but complex tilt-up and precast structures of 2 and 3 levels are now being built...Much more attention is given to large glass areas...This has led to the construction of tilt-up buildings with many large openings. In extreme cases, the exterior wall simply comprises spandrels (or beams) with very narrow integrally cast columns. [By being considered walls, these columns have avoided code requirements for ductility.] Moreover, under prevailing practice adjacent precast panels are rarely connected to each other, except for chord bars at the diaphragm, nor are they adequately connected to the foundation systems...While these buildings have not been tested by a major earthquake, we are convinced that some of them are potential collapse hazards." Damage will probably include separation between tilt-up units and the failure of the units themselves similar to non-ductile frames.

Principal damage curves for this large range of structures are shown in the following charts.

EXPECTED DAMAGE TO CONCRETE BUILDINGS



EXPECTED DAMAGE TO TILT-UP CONCRETE BUILDINGS



PART B--GATHERING DATA ON BUILDING STOCK

I. TECHNIQUES FOR GATHERING DATA

The effort needed to collect building stock information for a metropolitan area is best accomplished through a variety of data collection techniques. Several of these techniques were used to collect these data for the nine-county San Francisco Bay Area during 1984 and 1985. As a multi-county inventory, project staff could not even look at every building in the region, let alone do the type of in-depth structural analyses necessary to predict the response of individual buildings in earthquakes of various sizes. Thus, building-specific inventorying techniques were not used in this project.

A. Land Use Mapping

Because of the variety of data sources that were planned to be used, it was necessary to develop an overall framework in which the building data, once collected, could be placed. Early in the project, the decision was made to collect data for land units that consisted of identifiable land use areas within census tracts. This unit would simplify any future work in determining building occupancies.

Maps of 1980 census tracts were available in ABAG's files both as mylar overlays to 1:24,000-scale U. S. Geological Survey 7.5' quadrangle base maps and as a map file in ABAG's computer-based geographic information system.

The land use data were more difficult to obtain. The only consistent regionwide land use map was prepared by the U.S. Geological Survey as part of its nationwide LUDA map series, largely from aerial photography. The Bay Area map sheets, ranging in scale from 1:100,000 to 1:250,000, were based on photography from the mid-1970s. In addition, a joint U.S. Geological Survey/San Mateo County project produced a series of compatible land use maps for the mid-1970s at a scale of 1:24,000. Project staff drafted all of these land use maps onto mylar overlays of 1:24,000-scale U.S. Geological Survey 7.5' quadrangle base maps. Next, data on land use changes from 1975-1980 were added based on information gathered by staff of ABAG's population and employment projections program.

These land use map overlays were taken to the interviews with local building officials described in the following section. Either the official, or someone from the planning department, was able to review the maps and make appropriate changes to make them current as of the end of March, 1985. Although the maps prepared for these interviews based on U.S. Geological Survey data were a valuable means of encouraging discussion, they would not have been adequate for the purposes of this project without being reviewed by local government staff. The Survey maps commonly missed commercial strips along arterial streets, mislabelled areas of multi-story residential as commercial, and mistook non-urban uses of greenhouses and confined feeding operations as industrial. These errors might be expected given the reliance of the Survey on aerial photography to produce the maps.

Finally, the land use map overlays were digitized and converted to a map file in ABAG's computer-based geographic information system.

The land use categories used are listed in the left-hand column of Table B-1, below.

TABLE B-1--
PERCENTAGE OF SELECTED BUILDING TYPES
WITHIN LAND USE CLASSIFICATIONS

CENSUS TRACT NO.________
JURISDICTION:____________

IS TRACT SPLIT?____________
OTHER JURISDICTIONS:
____
____

TRACT POPULATION:________
TRACT POPULATION IN
JURISDICTION:________
TRACT EMPLOYMENT:________

LAND USE	WOOD FRAME (%)	LIGHT METAL (%)	MASONRY (%)	CONCRETE AND STEEL (%)	PRE-CAST CONCRETE (%)	MOBILE HOME-TYPE (%)
(11) RESIDENTIAL (111) 1 or less Du/hectare (112) 2-8 Du/hectare (113) 9 or more Du/hectare (114) Mobile Home Parks						
(12) COMMERCIAL & SERVICES (121) Retail & Wholesale (122) Commercial Outdoor Recreation (123) Education (1231) Elementary & Secondary (1232) Colleges & Universities (1233) Stadium (124) Hospitals, Rehab. Centers, Other Public Facilities (125) Military Installations (126) Other Public Institutions and Facilities (1261) Stadium (1262) Church (127) Research Centers (128) Office (129) Hotels						
(13) INDUSTRIAL (131) Heavy Industrial (132) Light Industrial						
(14) TRANSPORTATION,COMMUNICATION AND UTILITIES (141) Highways (142) Railways (143) Airports (144) Ports (145) Power lines (146) Sewage treatment plants						
(15) COMMERCIAL AND INDUSTRIAL COMPLEXES						
(16) MIXED URBAN OR BUILT-UP LAND (161) Transitional (162) Mixed use in buildings						
(17) OTHER URBAN OR BUILT-UP (171) Extensive recreation (1711) Golf courses (1712) Racetracks (172) Cemeteries (173) Parks (174) Open space-urban						
Non Urban: (223) Greenhouses (55) Sedimentation ponds (75) Mines, quarries and gravel pits (761) Sanitary land fills						

COMMENTS:

DATE____________/INITIALS__________

B. Interviews With Local Government Building Officials

The principal source of building stock data was a series of interviews with local government building officials/inspectors in the Bay Area. The interview process functioned as a valuable short-cut by avoiding the time-consuming process of even doing a *windshield* or *drive-through* survey of all of the buildings in the region. A large amount of useful information was collected, particularly on residential, industrial and outlying commercial areas. The interviews also had an auxiliary benefit; since the building officials could ultimately become one of the primary users of the information, their early involvement provided them with first-hand knowledge of how the data were obtained.

As might be anticipated, the building officials were not always the best source of information on one or more aspects of the project. For example, their usefulness was limited if they had not lived or worked in their community for a number of years. In those cases, they were able to provide us with someone else on the local staff to supplement their data, such as the fire chief, the public works director, or the director of community services. In addition, someone from the planning department was often contacted to review the land use maps.

The patience of these local personnel was phenomenal. However, the process often resembled more of an interrogation than an interview, largely because the data being requested were not collected as part of the day-to-day operation of a building department.

During the interviews, staff worked to fill out the forms (similar to that provided as Figure B-1) with data on percentages (based on square footages, rather than number of buildings) for each census tract occurring in the jurisdiction. A typical interview lasted 1-3 hours, including the time spent in reviewing the land use maps.

Building officials (or others interviewed) were often unable to provide data on the following classes of special or vital facilities:

- o public elementary and secondary schools, since the building permits for structures at these facilities have been issued by the Office of the State Architect for the past 50 years;
- o hospitals, since these structures also have been handled by the Office of the State Architect for the past 10 years;
- o State colleges and universities (over which they have no jurisdiction);
- o State penitentiaries and hospitals (again, over which they have no jurisdiction); and
- o Federal military facilities (again, over which they have no jurisdiction).

In addition, those interviewed were able to identify the census tracts where commercial or industrial building stock was extremely varied in both age and structural type. Although some were willing to take a guess at the building stock in these areas, many were unable or unwilling to provide estimates.

The gaps in the building data forms that appeared after the interviews were able to be filled through using a combination of other sources: special citywide inventories, *windshield* surveys, and facility-specific data. Each of these sources is described below. It is important to note that all of the data resulting from these other sources were synthesized and catalogued in the form of the data sheets shown as Figure B-1.

C. <u>Other Citywide Inventories</u>

A source of building data used in past building surveys is detailed maps prepared for fire insurance purposes by the Sanborn Company, or "Sanborn Maps." These maps are readily available for seven of the jurisdictions in the region: San Francisco, Oakland, San Jose, Berkeley, Alameda, Albany and Martinez. The maps were used extensively for Alameda, Albany and Berkeley because the maps were kept up to date. The maps in Martinez were used only to compile a list of seismically suspicious masonry buildings because they were twenty years old. Use of the maps in San Francisco, Oakland and San Jose would have been too time-consuming a task for this project. Other sources of data were available for those jurisdictions.

In 1984, Building Systems Development, Inc. performed a special survey of seismically suspicious buildings for the central downtown area of Oakland, as well as many of the commercial strips along major arterial streets. This inventory, funded by the National Science Foundation, consists of a collection of building data sheets that include street address, assessor's parcel number and a photograph. The sheets usually list the general type and date of construction, the use and size (number of stories, height, width and length). Other data on contents, configuration or construction components are included 20-25% of the time. These sheets were indexed to assessor's page maps. Inconsistencies between the index maps and data sheets were corrected by project staff. Incomplete listings of unreinforced masonry buildings in the downtown area also were corrected to the extent possible without reviewing the Sanborn maps for the City or the permit file. Because the study focused on "seismically suspicious" buildings in the downtown area, a major gap in the data on buildings not considered seismically suspicious existed in the outlying areas. Most industrial areas also were not surveyed. These two "gaps" were filled through a series of *windshield* surveys described later in this report.

Dames and Moore completed an inventory for San Francisco in 1985 as part of another research project funded by NSF. The project staff collected data for 15 districts. Each district is, in theory, fairly homogeneous in building stock. Project staff chose five to 12 typical blocks to sample in each planning area, for a total of 90 blocks. Project staff then went to the Sanborn maps and the computer printout of the Real Estate Atlas of San Francisco to extract statistics and obtain square footage for:

- seven different building types (wood frame, light metal, reinforced concrete block, masonry, old concrete, reinforced concrete, and steel);
- four different uses [residential (including hotels), commercial, industrial, and churches]; and
- three different heights (1-3, 4-6, and 7 or more stories).

These statistics for the sample blocks in each planning district were extrapolated to the 15 districts based on coverage on a land use map available from the city. Although the data for the sample blocks are highly accurate, much error can be introduced in the extrapolation process. In addition, because of the intent to extrapolate the data, the five building type categories Dames and Moore chose for data collection are very general. ABAG staff used the data directly, without conducting additional *windshield* studies. Any potential inaccuracies in the original data obviously remain. A major change in the data was made regarding hotels. Hotels are considered residential due to their 24-hour occupancy in the Dames and Moore study. Because ABAG staff considered hotels a commercial and service use and because the U.S. Census Bureau does not include hotel rooms as dwelling units unless 75% of the occupancy is permanent, the hotel data were taken out of the residential data. The hotel data were kept separate from the remaining commercial and service data, however, because of the issue of 24-hour occupancy. In addition, building districts were approximated by full census tracts even though the district boundaries were not coincident with tract boundaries.

Some types of city data were not included in this project. Data from assessors' files and permit files were not used directly because the records were dated, often incomplete, and time consuming to access. However, if someone else had used the data (such as was done on a selective basis for Oakland and San Francisco), the regional inventory includes those data. Some building-specific local data were reviewed while compiling the census tract level data, notably lists of seismically-suspicious masonry buildings compiled by local building departments. (It is planned that data from San Francisco's census of masonry buildings will be incorporated into this database at some future time.) Similar data on buildings over 75 feet high compiled by local fire departments for the State Fire Marshall's office also were reviewed.

Local aerial photography did not prove to be useful. However, to the extent that aerial photography served as a basis of the US Geological Survey's LUDA maps, general aerial photography was used indirectly in this project.

D. Windshield Surveys

When data could not be obtained in the interview process or readily from other research projects, *windshield* surveys were conducted. In this process, ABAG project staff, which included a U.C. Berkeley graduate student in architecture with extensive structural engineering background, slowly drove past the area in question. Although the use of this technique was not anticipated in the beginning of the project because it appeared to be potentially time-consuming, it ended up being used fairly extensively in older downtown commercial and older industrial areas. The data gathered proved to be similar in quality or only slightly less accurate than Sanborn map data, yet was far quicker to obtain. The task of collecting data on census tracts for Berkeley, Albany and Alameda using Sanborn maps took 2-8 person-hours per tract, while driving through and compiling data for similar areas in Oakland, San Jose and Richmond took 1-4 person-hours per tract. The major disadvantage of the data collected in this manner is that it is difficult to attach total square footage of building area to the percentage values.

For cities other than San Francisco, either Sanborn maps or *windshield* surveys were used to examine the commercial or industrial areas in roughly 15% of the census

tracts containing such areas. Because of the location of most of these tracts in central downtown areas, well over 15% of the commercial buildings in these cities have been examined.

E. Facility-Specific Data

For certain classes of special or vital facilities, the problem of building stock was approached on a regionwide basis, rather than city-by-city.

Data on State colleges and universities were obtained from a survey conducted by H.J. Degenkolb Associates for the State Seismic Safety Commission.

Public elementary and secondary schools, as well as community colleges, were assumed to be or behave similarly to wood-frame buildings due to the extensive regulations provided by the Field and Riley Acts. General data on private school construction were obtained from the Catholic Diocese of Oakland and the Diocese of San Jose.

Data on construction of major hospitals, penitentiaries and private colleges or universities were obtained through telephone conversations with the architecture and engineering staffs of the facilities themselves.

Information on military facilities, although it exists in Department of Defense records, proved too difficult to obtain for this project. Therefore, military facilities are excluded from analysis at this time.

F. Census and Employment Data

A major source of building data for housing stock in the area is the 1980 Census of Population and Housing. The most useful census data related to two data items: housing units by structure height and year structure built. For example, in a number of cases, the building official knew that all units in structures of a certain number of stories were of a particular structural type. Thus, by reviewing the data from the census, the percentage of units of a particular structural type could be calculated. The age data provided a clue to structural type as well.

However, since the census data were for 1980, rather than for 1985, some modifications were necessary. ABAG is responsible for projections of population and employment for the region. ABAG's projected household data was used to extrapolate the 1980 dwelling unit data to 1985. The ratio between households and dwelling units in 1985 was assumed to be the same as existed in 1980. (Checks of the Housing Vacancy Surveys published by the Federal Home Bank for the time proved this assumption reasonably accurate since the vacancy rate has not changed significantly.) The calculated dwelling unit difference between 1985 and 1980 was assigned to the age category of "1980s". The percentages for each age category could then be calculated by dividing the 1980 dwelling unit count for <1939, 1940s, 1950s, 1960s, and 1970s, as well as the calculated 1980s value, by the number of 1985 dwelling units. (Note that the 1980 Census has categories of 1970-1975, 1975-1978, and 1978-1979. These three categories were summed to create the 1970s category.) The percentages of dwelling units in low, medium and high story heights were calculated based on the 1980 data. This calculation assumed that the percentage of dwelling units in each

height category was similar in 1985 to 1980. (The only time this height distribution assumption was manually overridden was for Emeryville.)

The age percentages were then used to subdivide only the height category of "1-3 stories". Mid- and high- rise values were not subdivided. These files were then integrated into the building stock files and discrepancies were manually resolved. In addition, obvious errors in the census-derived residential files were corrected. The mean residential dwelling units value in the census can be updated from 1980 to 1985 using an inflation factor of 45.3% (obtained from the U.S. Bureau of Labor Statistics). However, if one assumes that the building (vs. land) is approximately two-thirds of this value, then the two correction factors cancel each other and the 1980 value can be used directly.

G. Employment Data

ABAG has access to a State Department of Finance file of employees by industrial/ commercial category (2-digit SIC code) by census tract for 1980. This confidential file, together with data on average square footage of building area per employee by employment category (from the Federal Highway Administration, 1970) was used to develop square footage and occupancy estimates for the region's buildings.

As with the census data, all of these estimates were updated from 1980 to 1985 using ABAG's projections estimates. The ratio between 1980 and 1985 for each SIC-code was based on the projected ratio for the industrial sector in which it falls. The SIC-code data was then aggregated to the employment groups as shown in Appendix B.

H. Priorities for Future Work

This inventory of Bay Area building stock should not be considered entirely accurate or complete. The areas where data are likely to be least accurate or complete, and therefore where data refinements would be most beneficial, are:

- outlying areas of San Jose, that is, beyond the 21 census tracts where windshield surveys were conducted;

- San Francisco, especially in the case of masonry buildings;

- military facilities, since data has not been included on these facilities;

- further checks on amount of commercial/service and industrial building stock in terms of square footage; and

- several smaller communities that are unincorporated or too small to have their own building department, since some *windshield* survey data indicate county officials may have overestimated the percentage of wood-frame commercial buildings.

The process of obtaining building stock data and resulting inaccuracies, especially in these areas, should be considered while reviewing and using the data contained in the following section. Inspite of these potential problems, the data are still potentially more accurate than used in previous estimate research.

II. BAY AREA BUILDING STOCK

The techniques described in the previous section resulted in several computer files:

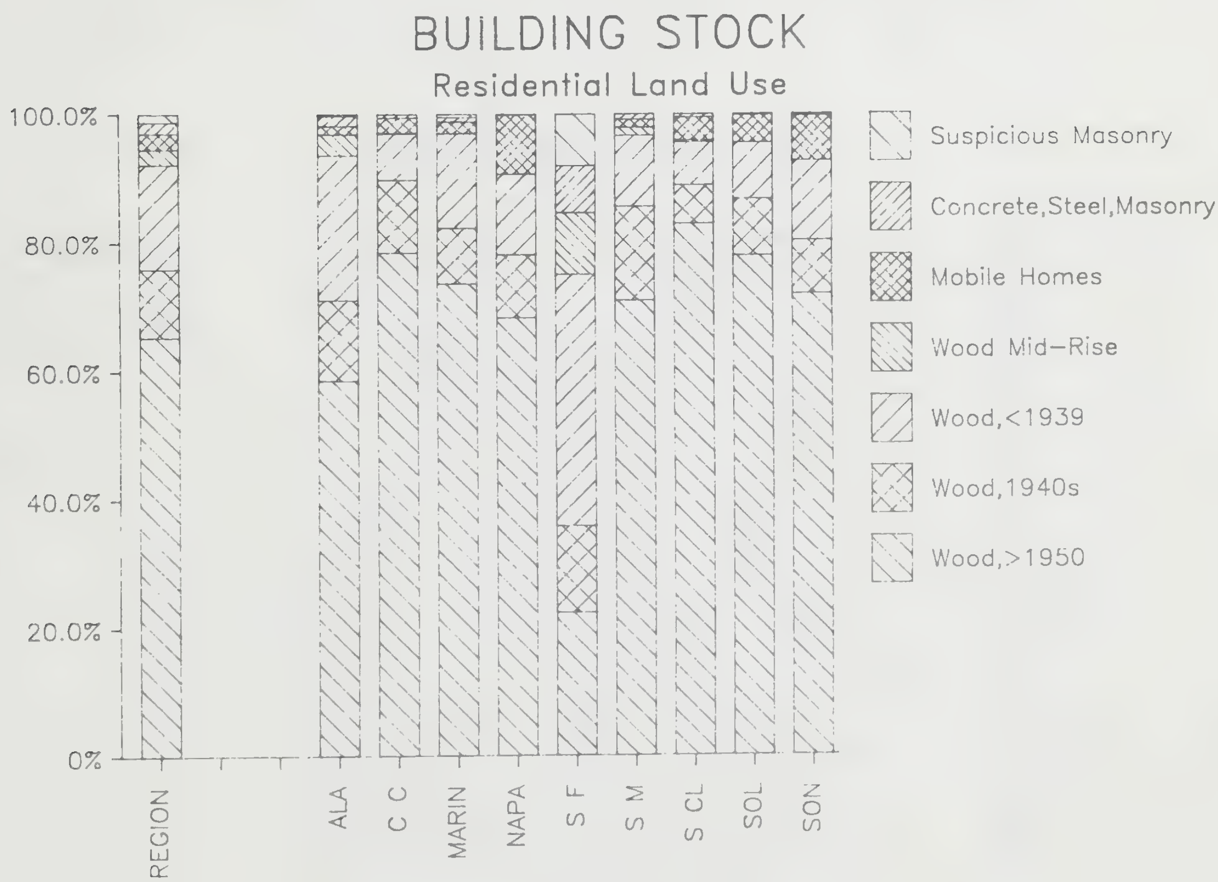
- o a March 1985 land use file with the categories listed in Table B-1 in the region's geographic information system;
- o a March 1985 file of building stock providing percent information for construction type for each land use within each of the 1189 land-based census tracts in the Bay Area;
- o a filed of estimated 1985 dwelling units and mean dwelling unit value for each of those tracts; and
- o a file of estimated 1985 square footage for several employment groups.

These files are too large to be included in this report. The results were aggregated to counties for three general land uses: residential, commercial and industrial. If more than one subcategory of a general land use occurred in a single census tract, the building stock percentages were weighted based on the relative land area occupied by each subcaterory. The resulting census tract percentages were converted to absolute values based on relative number of dwelling units (for residential) and on relative square footage (for commercial and industrial) and summed for all the census tracts in each county. New percentages were then calculated and are the basis of the following charts. Computer print-outs of the data or diskettes are available from ABAG staff.

A. Residential Building Stock

Wood frame one-to-three story buildings are by far the largest component of housing stock in the San Francisco Bay area, accounting for 92% of that building stock. If one sub-divides this category into three age groups (pre-1939, 1940s, and after 1950) to take advantage of the three damage curves that can be derived from the work of Rinehart and others (1976), the dominance of post-1950 construction, that subject to the lowest damage potential, is apparent. Wood frame mid-rise structures, usually three-story wood frame construction on top of a one-story concrete block or reinforced concrete parking level, tend to be a significant component of the residential building stock only in Alameda County, where it is the construction type for 3% of the dwelling units, and in San Francisco, where it makes up 9% of the building stock. (However, it is possible that the percentage of this construction type is over-estimated in San Francisco and the percentage of concrete, steel and reinforced masonry units is underestimated). Regionwide, wood frame mid-rise structures account for 2 1/2% of the housing stock.

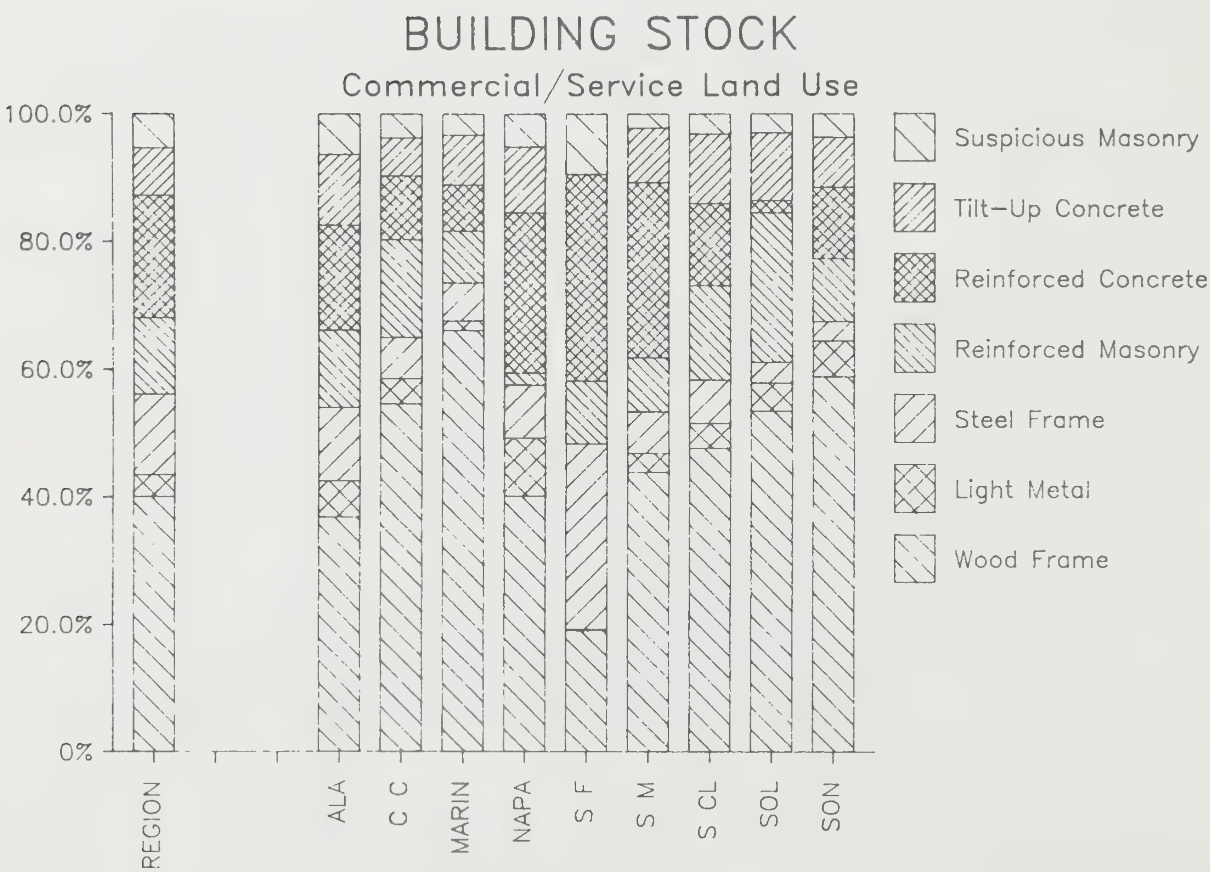
Mobile homes are the largest other component in the residential building stock. Although they are virtually non-existent in San Francisco, they constitute approximately 2 1/2% of the housing stock regionwide. They are particulary predominant in Santa Clara County and three of the North Bay counties--Napa, Solano and Sonoma. The special problems of these units in earthquakes because they are not placed on permanent foundations were discussed in PART A. These issues are discussed in greater detail in PART C, Section II.



B. Commercial/Service Building Stock

In this section, some generalizations have been made in the more detailed building stock data to aid in producing a regional summary. The general categories of *concrete/steel* and *masonry* were split half and half between reinforced concrete and steel frame, and reinforced and unreinforced masonry, respectively. In all cases but one this generalization affected less than 6% of the building stock. However, in San Francisco, *masonry* consists of approximately 19% of the commercial/service building stock.

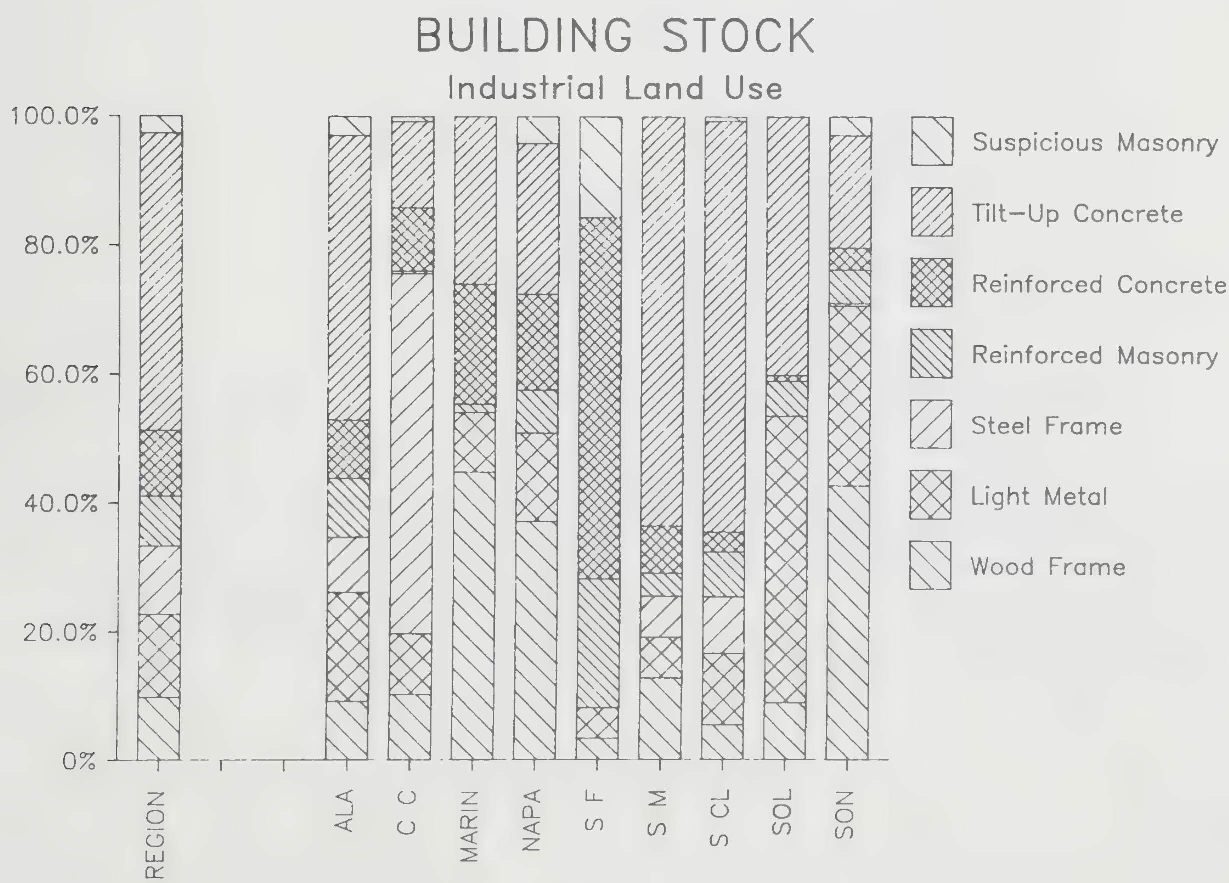
The predominate commercial/service building stock in the region is wood frame, accounting for 40% of the building stock. It is particularly dominate in Contra Costa County (55%) and the three North Bay counties of Marin (66%), Solano (54%) and Sonoma (59%), and small in San Francisco (19%). The next most dominate construction type is reinforced concrete, accounting for 19% of the regional building stock. The counties of Napa, San Francisco and San Mateo exceed this average. Light metal accounts for 3 1/2% of the regional building stock. Suspicious masonry only accounts for 5% of the building stock. However, in San Francisco, it accounts for 0-19%, for an estimated 9% of the commercial building stock. Steel frame accounts for 13% of the regional building stock, yet 29% in San Francisco. Tilt-up concrete accounts for 7% of the regional building stock. (Again, note that tilt-up concrete was not identified in San Francisco except in rare instances.) However, tilt-up exceeded 10% in Alameda, Napa, Santa Clara, and Solano counties.



C. Industrial Building Stock

For this section, as with the previous one, the general categories of *concrete/steel* and *masonry* were split half and half between reinforced concrete and steel frame, and reinforced and unreinforced masonry, respectively. In most cases, this generalization affected well under 5% of the building stock. However, in Napa County, 8% of the industrial building stock is listed in the inventory as *masonry* (largely older wineries) and in San Francisco, 31% of the industrial building stock is listed as *masonry*. Finally, no distinction was made in the Dames and Moore study of San Francisco described earlier between tilt-up concrete and other reinforced concrete structures. Therefore, in the inventory tilt-up concrete is included with reinforced concrete in the industrial building stock for the summaries.

Regionwide, at least 46% of the industrial building stock is tilt-up concrete. Correcting for inventory data gaps in San Francisco should bring the total to close to 50%. The amount of tilt-up construction in San Mateo and Santa Clara counties is 63+%. Suspicious masonry amounts to 3% of the building stock. However, from 0-31%, or an estimated 16%, of the building stock in San Francisco is this type of construction. Wood frame construction amounts to 10% of the buildings regionwide. However, it is a major component of building stock in the North Bay counties of Marin (45%), Napa (37%) and Sonoma (43%) counties. Light metal construction amounts to 13% of the industrial building stock in the region, but amounts to 45% of the building stock in Solano and 28% of the construction in Sonoma counties. Steel frame amounts to only 11% of the industrial building stock in the region, yet 56% in Contra Costa County, largely due to its extensive use in the petrochemical industry. Reinforced concrete amounts to 10% of the regional building stock, yet 56% of the building stock of San Francisco. Even subtracting any estimated error due to including tilt-up concrete leaves a percent that is still quite large.



PART C--USES OF BUILDING DATA TO DEFINE EARTHQUAKE HAZARDS AND THEIR MITIGATION

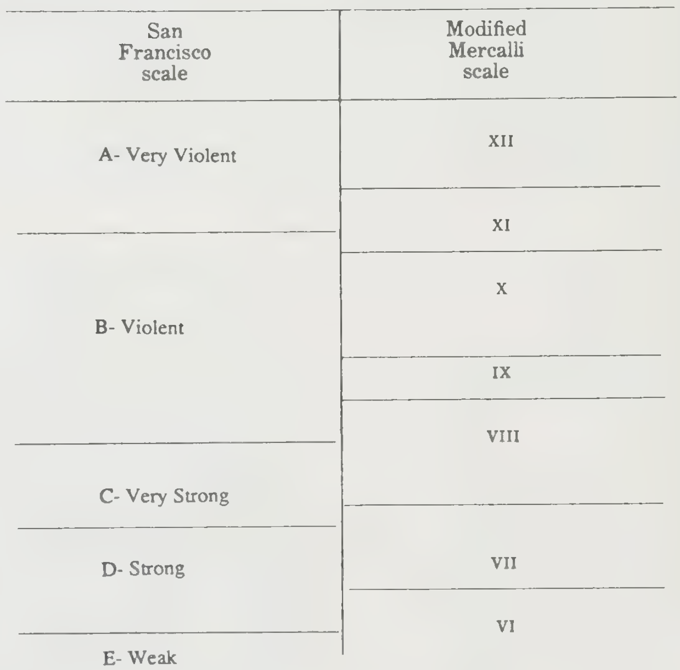
I. LAND USE VS. MAXIMUM GROUND SHAKING INTENSITY

A. Method

One of the simplest ways to use the data gathered in this project for estimating the size of the earthquake risk in a metropolitan area is through a three-way tabulation of hectares (100 meters square or 2.47 acres) of (a) each land use exposed to (b) each ground shaking intensity for a scenario earthquake for (c) each census tract in the region.

A variation of this calculation was performed using Bay Area data. Rather than performing the calculation using a single earthquake event, such as a great earthquake on either the Hayward or San Andreas fault, a MAXIMUM ground shaking map was used. This decision was made after an extensive review of the advantages and disadvantages of using a single earthquake. Using the maximum intensity map avoids the problems of East Bay jurisdictions becoming overly confident if a San Andreas scenario were used and the Peninsula becoming overly confident if a Hayward scenario were used. The main disadvantage, not being able to obtain regional totals, was not believed significant.

The map was prepared by ABAG staff by overlaying a series of 31 intensity maps, one for each of the 31 active faults in the San Francisco Bay Area. The map is based on the San Francisco intensity scale, rather than the more commonly used modified Mercalli scale because the attenuation relationships (the decrease of intensity of shaking with increased distance from the faults) are based on data from the 1906 earthquake. The relationship between the two scales is shown here. Further information on this process is contained in ABAG's Earthquake Mapping Project Working Paper #17. The map used is shown on the following page.



The complex cross-tabulation process of examining three files at once (land use, intensity, and census tract) was made possible due to the existence of a sophisticated geographic information system for the San Francisco Bay Area known as BASIS (for Bay Area Spatial Information System). Although the data in BASIS is ABAG's, the computer support for BASIS, including both the computer system on which the data are stored and the specialized programs or software used to manipulate the files, is the responsibility of GeoGroup Corporation of Berkeley, California.

MAXIMUM GROUND SHAKING INTENSITY

Ozalid copies available at 1:250,000

The results of this cross-tabulation, on a census tract by census tract basis, were then aggregated to the county and regional level. The results for most of the individual land uses also were combined into four general categories--residential, educational, commercial, and industrial--as described in Table C-1, below. Not all land use sub-categories included in Table B-1 were used in this process. Also note that these aggregations are based on land area, not on relative number of dwelling units or square footage of buildings.

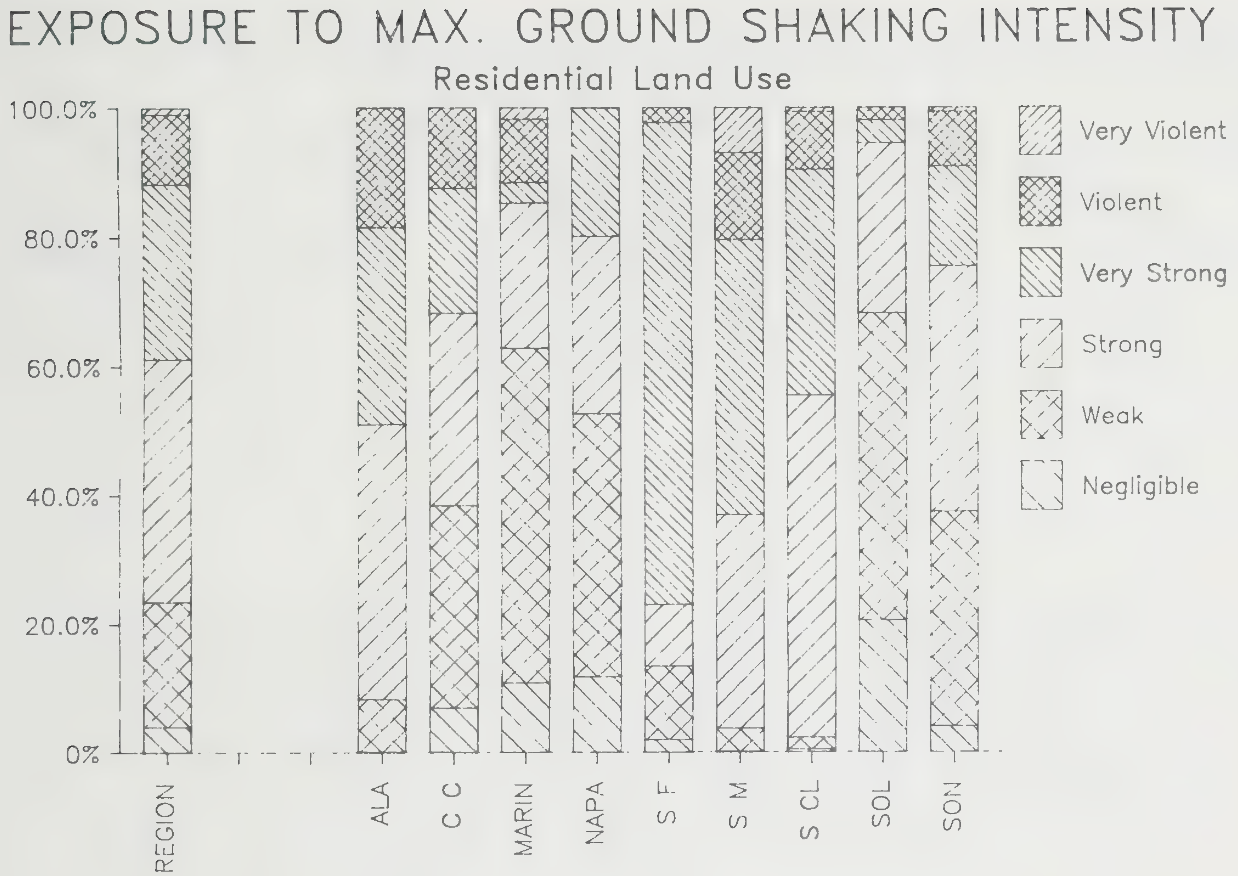
TABLE C-1--

PERCENT OF LAND USE AREA INCLUDED IN LAND USE GROUPS

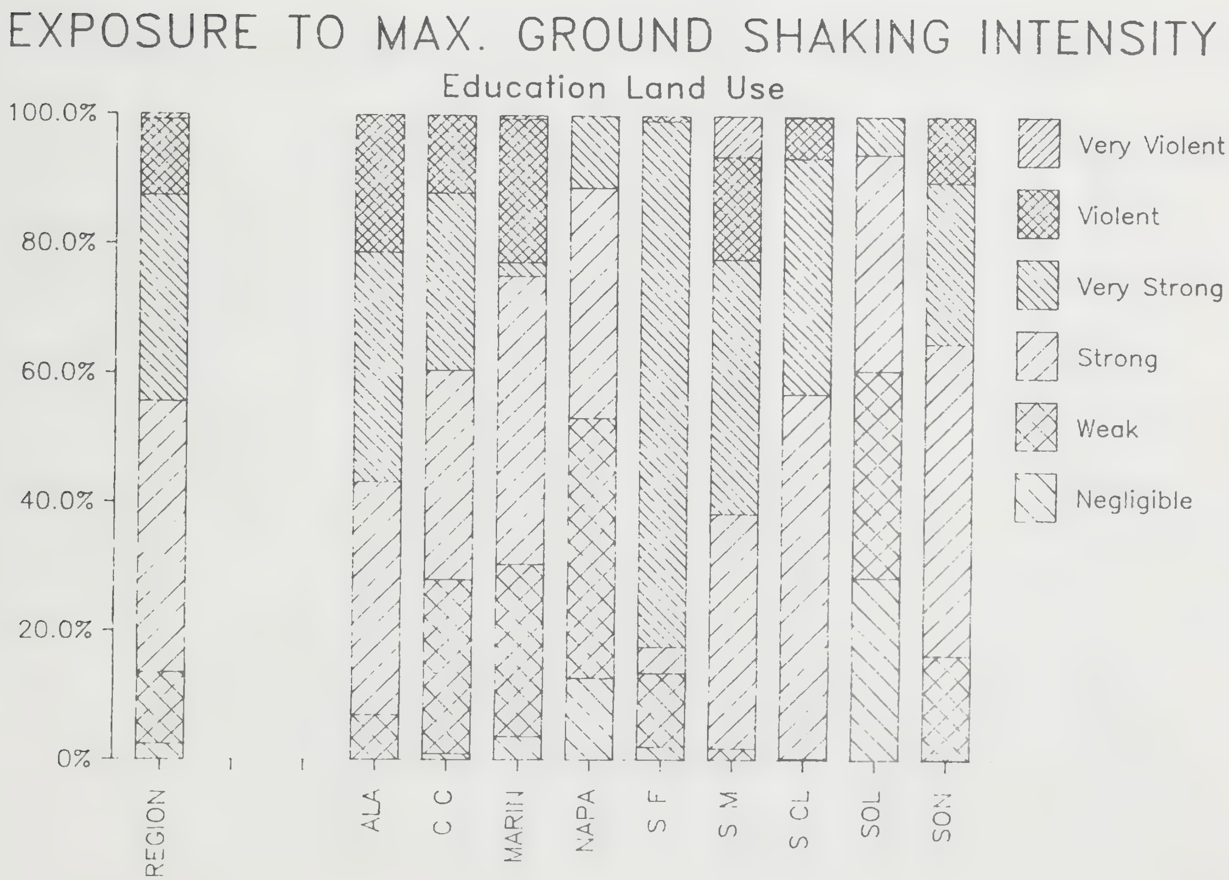
Land Use Group	Land Use Codes	Percent of Land Area Included
Residential	(11) Residential	100%
	(111) 1 or Less DU/Hectare	10%
	(112) 2-8 DU/Hectare	50%
	(113) 9 or More DU/Hectare	100%
	(114) Mobile Home Parks	100%
	(16) Mixed Residential & Commercial	50%
	(161) Mixed Use of Land	50%
	(162) Mixed Use in Buildings	50%
Educational	(123) Education	100%
	(1231) Elementary & Secondary	100%
	(1232) Colleges & Universities	100%
Commercial & Services	(12) Commercial & Services	100%
	(121) Retail & Wholesale	100%
	(122) Commercial Outdoor Recreation	100%
	(124) Hospitals and Rehabilitation Centers	100%
	(126) Other Public Institutions and Facilities	100%
	(1261) Churches & Synagogues	100%
	(127) Research Centers	100%
	(128) Offices	100%
	(129) Hotels	100%
	(15) Commercial & Industrial Complexes	50%
	(16) Mixed Residential & Commercial	50%
	(161) Mixed Use of Land	50%
	(162) Mixed Use of Buildings	50%
Industrial	(13) Industrial	100%
	(131) Heavy Industrial	100%
	(132) Light Industrial	100%
	(15) Commercial & Industrial Complexes	50%

B. Results

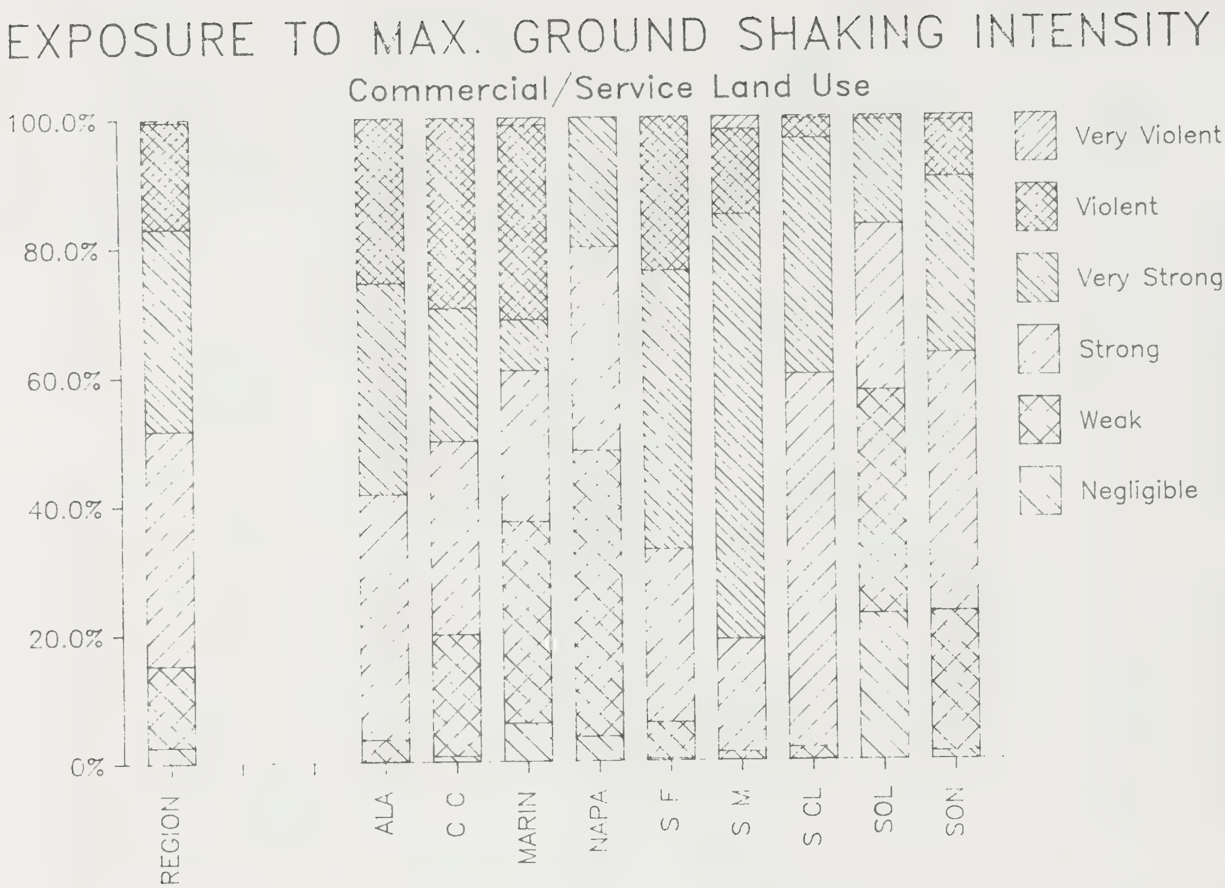
The maximum level of ground shaking to which four general land use types could be in the San Francisco Bay Area is summarized in the following four bar charts. At the regional level, industrial lands could be exposed to the highest intensities, followed by commercial, education, and residential lands. This trend continues to some extent for ALL of the individual counties. Another significant relationship also appears. The land in San Francisco and San Mateo counties tends to be exposed to higher intensities than the regional average for all land uses. The urban land in Alameda and Santa Clara counties tends to be at the regional average for intensity exposure and the urban land in Contra Costa and the four northern counties tends to be exposed to lower intensities of shaking.

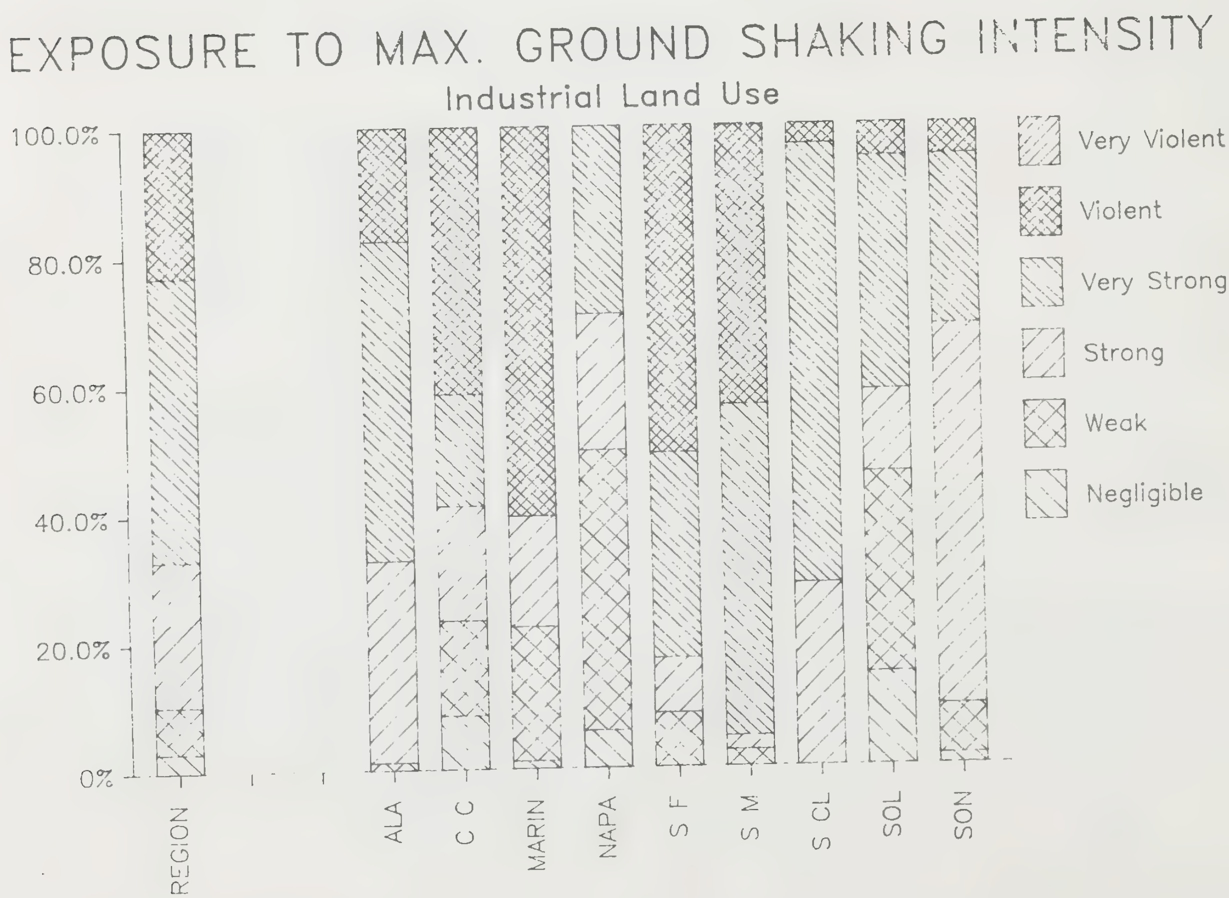


EXPOSURE TO MAX. GROUND SHAKING INTENSITY
Residential Land Use
100.0%
80.0%
60.0%
40.0%
20.0%
0%
REGION
ALA
C C
MARIN
NAPA
S F
S M
S CL
SOL
SON
Very Violent
Violent
Very Strong
Strong
Weak
Negligible



EXPOSURE TO MAX. GROUND SHAKING INTENSITY
Education Land Use
100.0%
80.0%
60.0%
40.0%
20.0%
0%
REGION
ALA
C C
MARIN
NAPA
S F
S M
S CL
SOL
SON
Very Violent
Violent
Very Strong
Strong
Weak
Negligible

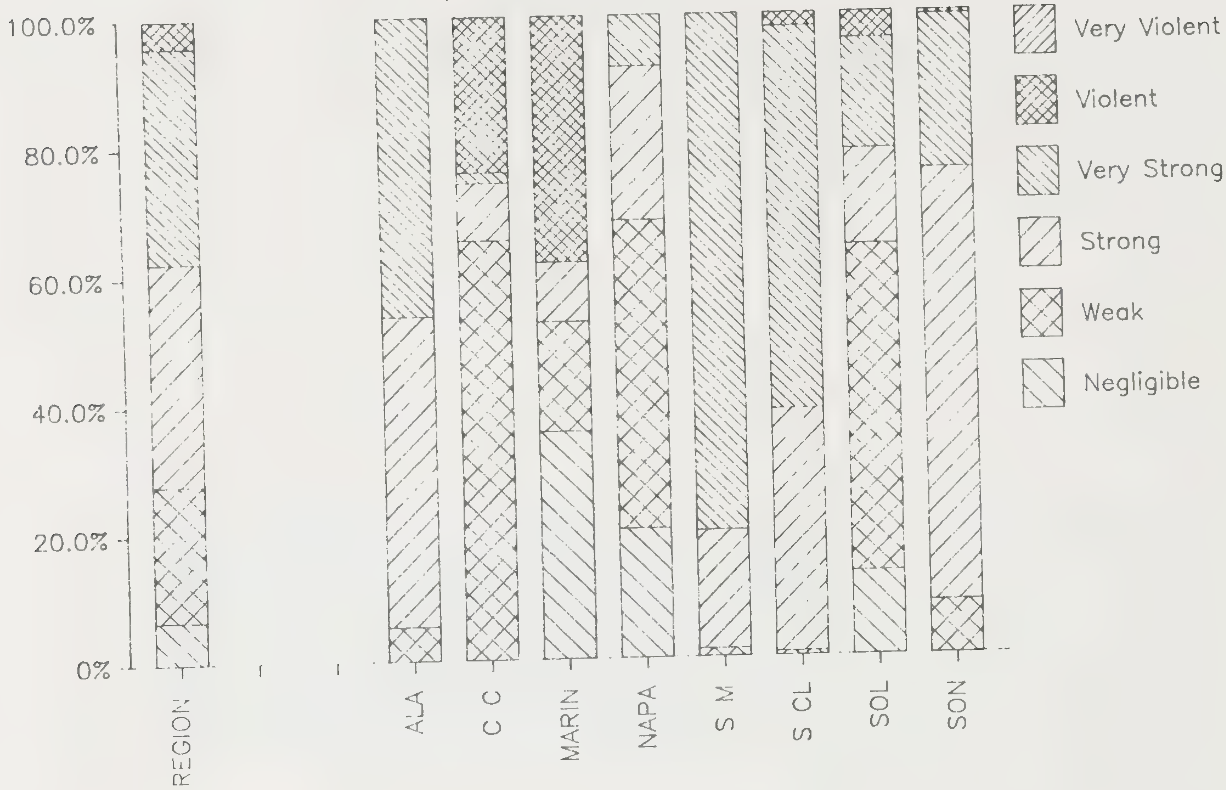

EXPOSURE TO MAX. GROUND SHAKING INTENSITY
Commercial/Service Land Use
100.0%
80.0%
60.0%
40.0%
20.0%
0%
REGION
ALA
C C
MARIN
NAPA
S F
S M
S CL
SOL
SON
Very Violent
Violent
Very Strong
Strong
Weak
Negligible


EXPOSURE TO MAX. GROUND SHAKING INTENSITY
Industrial Land Use
100.0%
80.0%
60.0%
40.0%
20.0%
0%
REGION
ALA
C C
MARIN
NAPA
S F
S M
S CL
SOL
SON
Very Violent
Violent
Very Strong
Strong
Weak
Negligible

Two other comparisons were made, the first one being between mobile home parks and general residential land. On a regionwide basis, there is a tendency of mobile home parks to be exposed to slightly lower intensities of shaking than general residential land. At the county level, such relationships were less obvious due to considerable variations in the precise levels of shaking. Secondly, a comparison was made between land used for hospitals and general commercial land. Hospitals tend to be exposed to lower levels of intensity on a regional basis. This relationship holds true at the county level, with the exceptions of Santa Clara and Sonoma counties, where hospitals are exposed to stronger shaking.

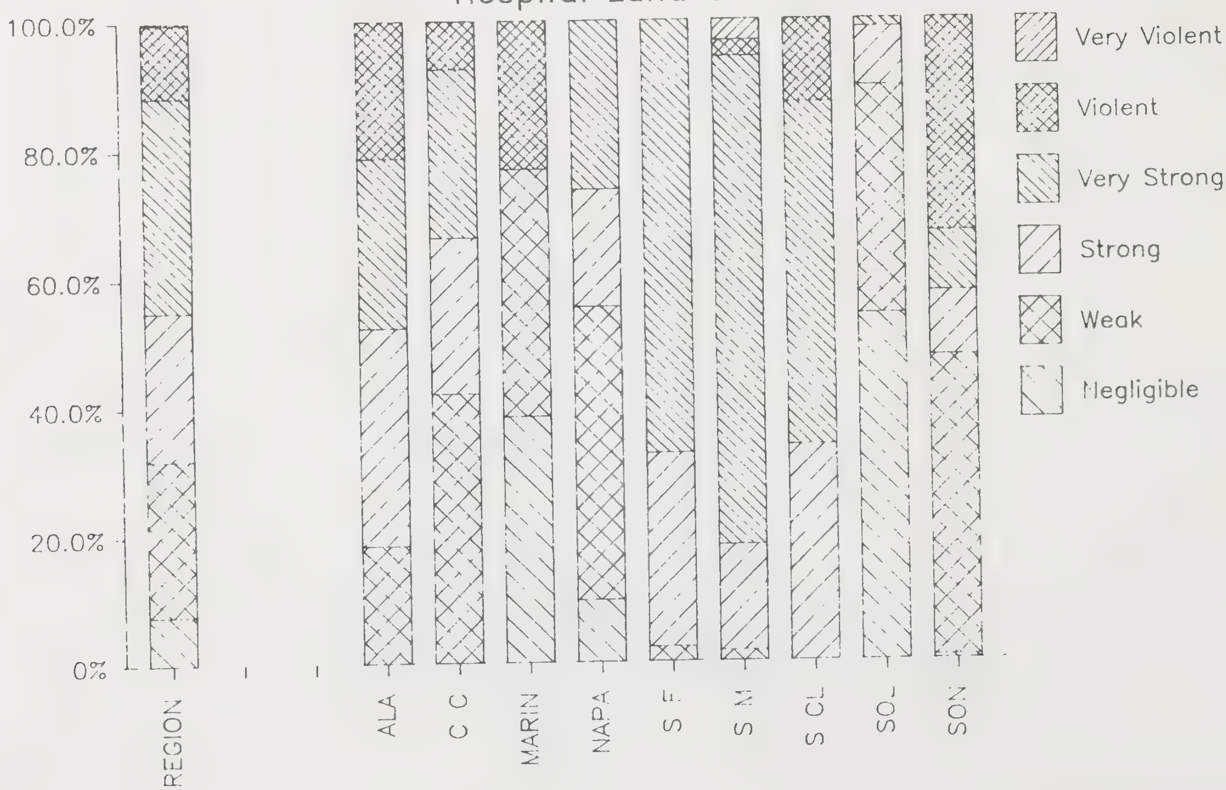
EXPOSURE TO MAX. GROUND SHAKING INTENSITY

Mobile Home Parks



EXPOSURE TO MAX. GROUND SHAKING INTENSITY

Hospital Land Use



II. SPECIAL PROBLEMS WITH SELECTED BUILDING TYPES

While collecting data on existing building stock, special care was taken to gather existing data on three building types: seismically suspicious masonry, tilt-up concrete, and mobile homes. These data are summarized in this section.

A. Seismically-Suspicious Masonry Buildings

There are several thousand masonry building in the nine-county Bay Area that are probably unreinforced or minimally reinforced. ABAG survey data are summarized below.

County	Number of Seismically-Suspicious Masonry Buildings
Alameda	830 - 980
Contra Costa	170 - 270
Marin	90 - 240
Napa	50 - 90
San Francisco	2058
San Mateo	200 - 240
Santa Clara	520 - 590
Solano	90 - 120
Sonoma	680 - 760
Total	4700 - 5400

Note that 40% of all of these buildings are probably located in San Francisco. The other big cities with large numbers of these buildings are Santa Rosa and Oakland with about 500 each, followed by San Jose with about 200. Berkeley, Petaluma and San Carlos have about 100 each. A complete list of survey data is in Appendix E.

Several Bay Area cities have initiated retrofitting programs. Santa Rosa's retrofit ordinance (passed following the Santa Rosa earthquake) has resulted in at least 128 of their approximately 500 remaining suspicious masonry building being retrofitted. In enforcing the ordinance, the building department makes use of opportunities, such as changes of ownership or occupancy, to initiate rehabilitation requirements. The highest priority for rehabilitation were buildings of high occupancy or fronting busy streets.

A less well publicized program was initiated in nearby Sebastopol at about the same time. Unlike Santa Rosa, Sebastopol created a list of all 39 of its suspect masonry buildings. Finding that they were all clustered in the commercial downtown area, it devised a lottery system for requiring retrofitting. Each year over a 10-year period four names were drawn. The "winners" of this lottery were then required to submit a structural report and plan for rehabilitation within 2 years and to have completed remedial work within additional 3 years. To date, 24 of the 39 buildings in that community have been retrofitted. A crash program in Morgan Hill following the Hall

Valley/Morgan Hill earthquake in 1984 resulted in three of their six unreinforced masonry buildings being demolished and the remaking three being retrofitted.

Palo Alto passed an ordinance in January 1986 that requires building owners to file structural engineering reports on suspicious masonry buildings. The City believes that the reporting requirement will cause owners to strengthen buildings even though they are not required to do so. Although originally designed to apply to a variety of potentially hazardous buildings, the final version of the ordinance focuses on masonry buildings.

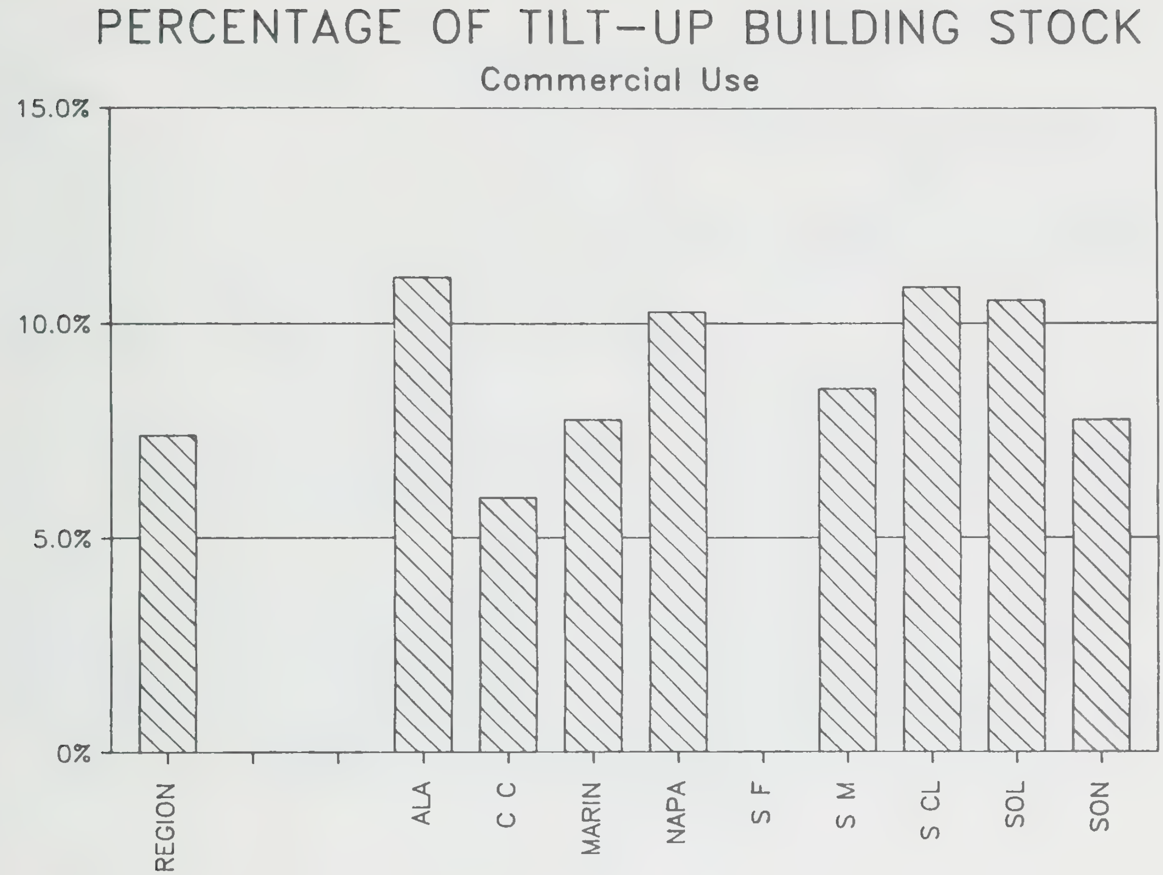
In 1985, San Francisco initiated a program to inventory all non-wood frame buildings in the City constructed prior to 1951. The results of the survey will be used to help design a program to reduce this hazard.

Several cities have reduced the hazard of unreinforced masonry buildings without using formal ordinances. One technique is to refuse to issue an occupancy permit once such a building becomes vacant until some rehabilitation work has been completed. Another is to demolish the buildings as part of an urban renewal or redevelopment program. In addition, building department personnel have convinced owners to do structural strengthening as part of the architectural work required in a redevelopment district using the argument of avoiding "throwing good money at a bad building."

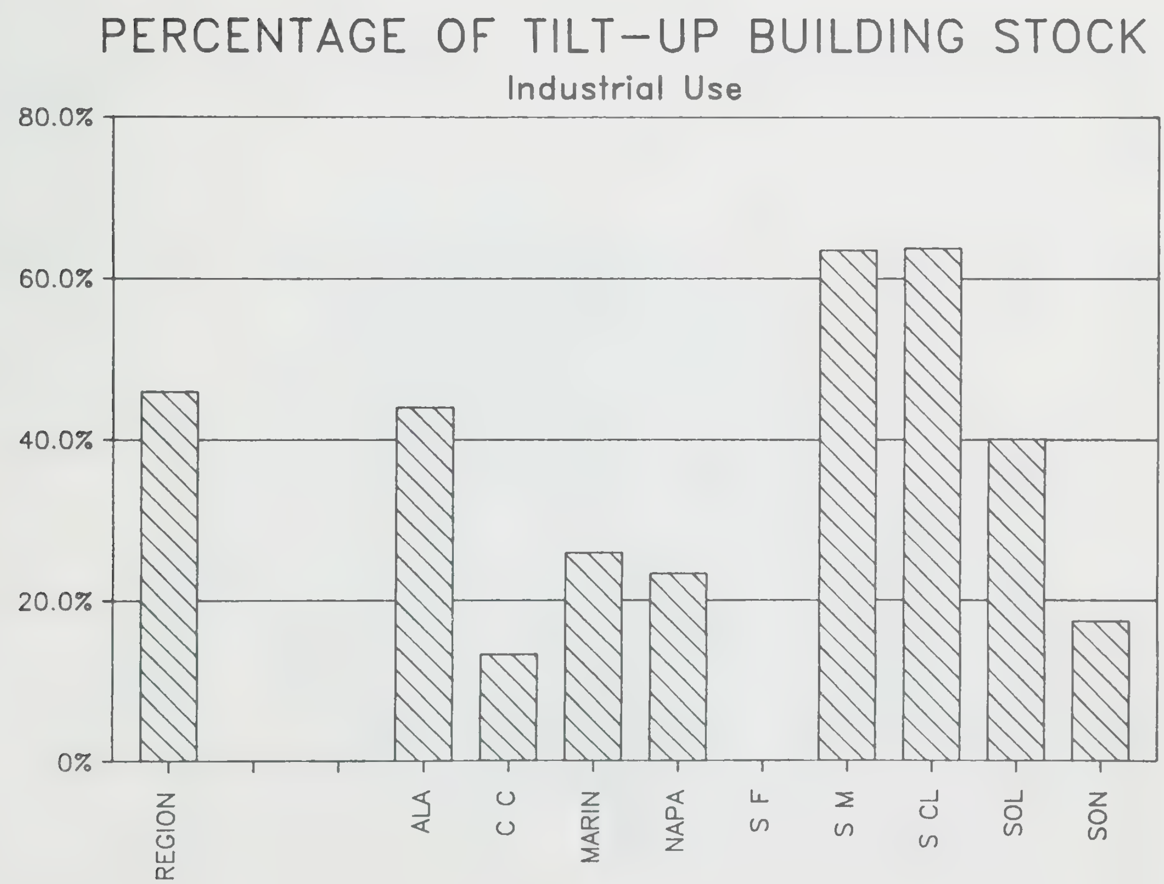
B. Tilt-Up Concrete Buildings

As shown in the figures below, tilt-up concrete buildings are a significant percentage of the industrial and commercial building stock in the nine Bay Area counties. Although ABAG has no data on the absolute number of such buildings, project staff has estimated that they may account for 70 million square feet of industrial and 50 million square feet of commercial buildings.

Although no community has adopted requirements in excess of the Uniform Building Code for new construction of tilt-up buildings, or any rehabilitation requirements, several companies have initiated retrofitting programs on their own. Company officials have felt strongly that in competitive businesses, they cannot afford to be out of operation for several weeks. The Committee on Hazardous Buildings of the Seismic Safety Commission has expressed extreme concern on the proliferation of these buildings (Report No. SSC 85-04, 1985).



PERCENTAGE OF TILT-UP BUILDING STOCK
Commercial Use
15.0%
10.0%
5.0%
0%
REGION
ALA
C C
MARIN
NAPA
S F
S M
S CL
SOL
SON



PERCENTAGE OF TILT-UP BUILDING STOCK
Industrial Use
80.0%
60.0%
40.0%
20.0%
0%
REGION
ALA
C C
MARIN
NAPA
S F
S M
S CL
SOL
SON

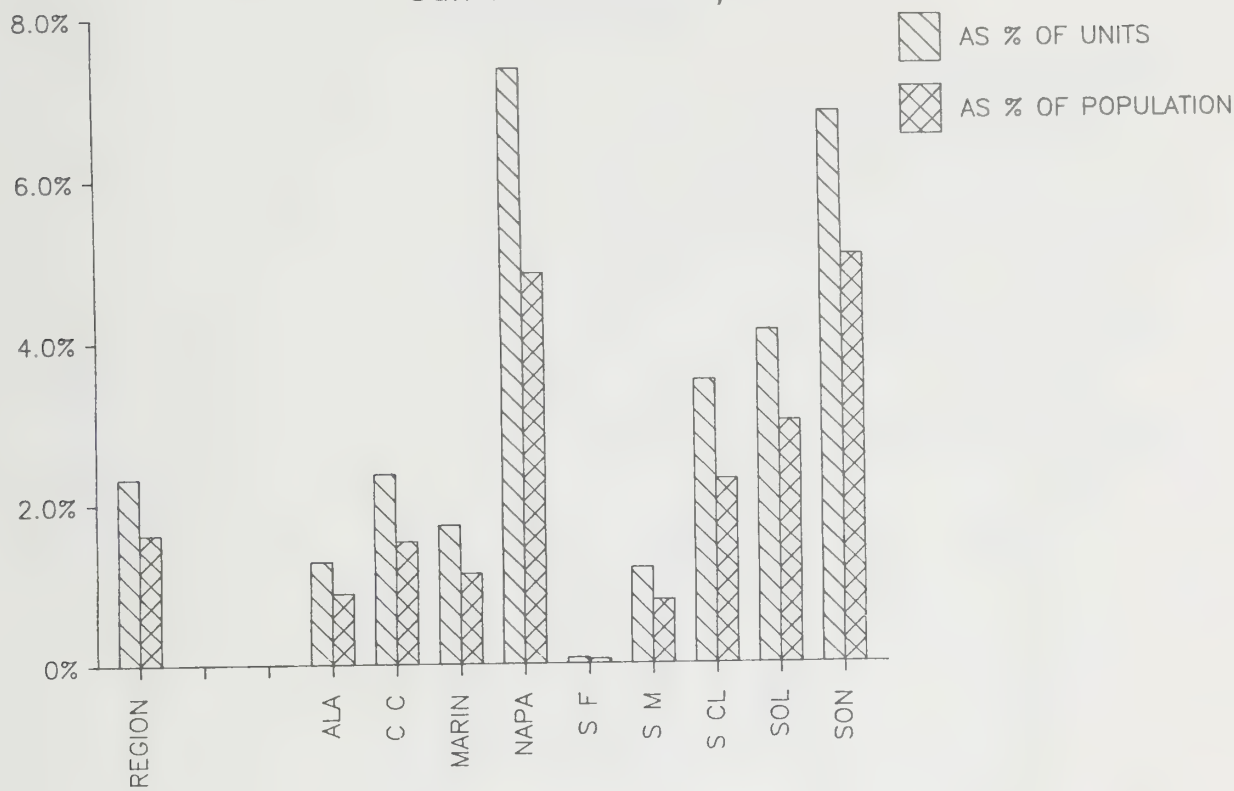
C. Mobile Home Housing Stock

Mobile home units statistically tend to be subject to greater damage from equivalent intensities of shaking than do wood-frame dwellings. In an earthquake, the typical jacks on which the units are placed will tip, or units will fall off some or all of their supports. It is not uncommon for the jacks to punch holes through the floor of the units in this process. The unit itself usually remains relatively undamaged and repair costs, as indicated in PART A, are relatively small, costing anywhere from $500 to $2000. The major problem is that even at these relatively low damage amounts, the unit becomes uninhabitable. It must be returned to a foundation, releveled, and reconnected to utilities. Consequently, ABAG staff have identified the relative amount of mobile homes in the region. It should be noted that these charts are based directly on 1980 census data, rather than undergoing any of the extrapolation that occurred to create the residential data cited in PART B.

The State Department of Housing and Community Development is required by a law passed in 1980 to develop standards, test products and certify seismic bracing for supporting mobile homes. Approximately ten products will have been tested by the end of 1986. Efforts are also underway to require the State Department of Housing and Community Development to notify ALL mobile home owners that certified bracing for supporting mobile homes will be available for purchase as part of AB 3917.

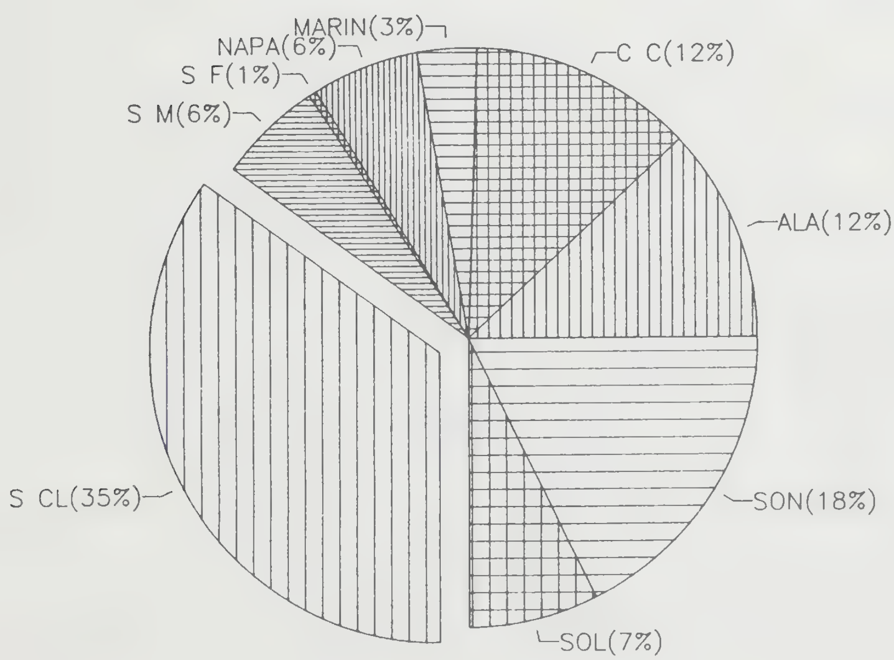
MOBILE HOME HOUSING STOCK

San Francisco Bay Area



DISTRIBUTION OF MOBILE HOMES

San Francisco Bay Area



LOSS ESTIMATE FOR A "TYPICAL" CENSUS TRACT

ASSUMPTIONS

Amount of Building Stock in
- Residential - 1,000 dwelling units
- Education - 100,000 square feet
- Commercial - 150,000 square feet
- Industrial - 175,000 square feet

Intensity (SFI) Exposure in Sample Track
- Residential - 10% (I=B); 40% (I=C); 50% (I=D)
- Education - 100% (I=C)
- Commercial - 25% (I=B); 50% (I=C); 25% (I=D)
- Industrial - 40% (I=B); 60% (I=C)

Building Stock in Sample Tract

Residential -	-- 85% WD (Wood--30% <1940, 15% 1940s, 40%> 1950);
	-- 10% MH (Mobile Home);
	-- 5% RC (Reinforced Concrete).
Education -	--100% WD (Wood Frame).
Commercial -	-- 5% LM (Light Metal);
	-- 35% WD (Wood Frame);
	-- 15% SF (Steel Frame);
	-- 10% RM (Reinforced Masonry);
	-- 5% RC (Reinforced Concrete);
	-- 20% TU (Tilt-Up Concrete);
	-- 10% SS (Seismically Suspicious Masonry).
Industrial -	-- 20% LM (Light Metal);
	-- 15% SF (Steel Frame);
	-- 10% RM (Reinforced Masonry);
	-- 5% RC (Reinforced Concrete);
	-- 50% TU (Tilt-Up Concrete).

Assumed Loss Curve Values*,**

Construction	San Francisco Intensity					
	<E Negligible	E Weak	D Strong	C Very Strong	B Vio-lent	A*** Very Violent
LM	0	0	1.92	3.35	5.11	6.87
WD (general)	0.25	2.11	4.47	6.28	9.04	11.80
≥ 1950	0.25	2.11	4.54	6.43	9.30	12.17
WD 1940s	0.25	2.14	5.34	7.08	10.17	13.26
WD <1940	0.25	3.76	7.20	9.63	13.97	18.31
MH	1.00	2.50	5.00	9.50	12.33	15.16
SF	0	0	2.00	5.94	10.75	15.56
RM	0	2.00	7.17	11.04	15.78	20.52
RC	0	2.40	9.93	15.59	22.49	29.39
TU	0	2.50	10.33	17.09	24.72	32.35
SS	0	4.00	14.33	22.09	31.56	41.03

Average Replacement Cost Values*,****

For a dwelling unit in Sample Tract:

$80,000 (excluding land; building only)

For commercial/industrial structures

Light Metal (LM)	$32/sq. ft. commercial; $22/sq. ft. industrial
Wood Frame (WD)	$45/sq. ft. ($40-$50/sq. ft.)
Steel Frame (SF)	$70/sq. ft. ($60-$80/sq. ft.)
Reinforced Masonry (RM)	$44/sq. ft. ($40-$50/sq. ft.)
Reinforced Concrete (RC)	$66/sq. ft. ($55-$75/sq. ft.)
Tilt-Up Concrete (TU)	$39/sq. ft. commercial; $23/sq. ft. industrial
Suspicious Masonry (SS)	(same as reinforced masonry)

*Note: these values remain constant and do not vary by census tract.

**The values here are based on curves described in PART A; for method of transfer from MMI see Appendix D.

***Values obtained by extrapolation. Change from SSI C --> B assumed equal to change from SSI B --> A.

****Based on cost ranges estimated by Lee Saylor, Inc.

SAMPLE CALCULATION

Residential Loss=

That is,	.40 (of WD 50)	x .10 (of I_B)	x .0930 loss	
	+.40 (WD 50)	x .40 (I_C)	x .0643 loss	
	+.40 (WD 50)	x .50 (I_D)	x .0454 loss	
	+.15 (WD 40)	x .10 (I_B)	x .1017 loss	
	+.15 (WD 40)	x .40 (I_C)	x .0708 loss	x 1,000 DUS x $80,000/du
	+.15 (WD 40)	x .50 (I_D)	x .0534 loss	
	+.30 (WD 30)	x .10 (I_B)	x .1397 loss	= $5,893,720
	+.30 (WD 30)	x .40 (I_C)	x .0963 loss	
	+.30 (WD 30)	x .50 (I_D)	x .0720 loss	
	+.10 (MH)	x .10 (I_B)	x .1233 loss	
	+.10 (MH)	x .40 (I_C)	x .0950 loss	
	+.10 (MH)	x .50 (I_D)	x .0500 loss	
	+.05 (RC)	x .10 (I_B)	x .2249 loss	
	+.05 (RC)	x .40 (I_C)	x .1559 loss	
	+.05 (RC)	x .50 (I_D)	x .0993 loss	

Education loss =

That is, 1.00 (WD) x 1.00 (I_c) x .0628 loss x 45 $/sq. ft. x 100,000 sq. ft. = $282,600

Commercial Loss =

That is,	.05 (of LM)	x .25 (of I_B)	x .0511 loss	
	.05 (LM)	x .50 (I_C)	x .0335 loss	x 32 $/sq. ft. x 150,000 sq. ft. = $8,238
	.05 (LM)	x .25 (I_D)	x .0192 loss	
	.35 (WD)	x .25 (I_B)	x .0904 loss	
	.35 (WD)	x .50 (I_C)	x .0628 loss	x 45 $/sq. ft. x 150,000 sq. ft. = $153,976
	.35 (WD)	x .25 (I_D)	x .0447 loss	
	.15 (SF)	x .25 (I_B)	x .1075 loss	
	.15 (SF)	x .50 (I_C)	x .0594 loss	x 70 $/sq. ft. x 150,000 sq. ft. = $96,981
	.15 (SF)	x .25 (I_D)	x .0200 loss	
	.10 (RM)	x .25 (I_B)	x .1578 loss	
	.10 (RM)	x .50 (I_C)	x .1104 loss	x 44 $/sq. ft. x 150,000 sq. ft. = $74,300
	.10 (RM)	x .25 (I_D)	x .0717 loss	
	.05 (RC)	x .25 (I_B)	x .2249 loss	
	.05 (RC)	x .50 (I_C)	x .1559 loss	x 66 $/sq. ft. x 150,000 sq. ft. = $78,705
	.05 (RC)	x .25 (I_D)	x .0993 loss	
	.20 (TU)	x .25 (I_B)	x .2472 loss	
	.20 (TU)	x .50 (I_C)	x .1709 loss	x 39 $/sq. ft. x 150,000 sq. ft. = $202,498
	.20 (TU)	x .25 (I_D)	x .1033 loss	
	.10 (SS)	x .25 (I_B)	x .3156 loss	
	.10 (SS)	x .50 (I_C)	x .2209 loss	x 44 $/sq. ft. x 150,000 sq. ft. = $148,616
	.10 (SS)	x .25 (I_D)	x .1433 loss	
				= $763,314

Industrial Loss*

That is,	.20 (of LM)	x .40 (I_B)	x .0511 loss	x 22 $/sq. ft. x 175,000 sq. ft. = $31,216
	.20 (LM)	x .60 (I_C)	x .0335 loss	
	.15 (SF)	x .40 (I_B)	x .1075 loss	x 70 $/sq. ft. x 175,000 sq. ft. = $144,501
	.15 (SF)	x .60 (I_C)	x .0594 loss	
	.10 (RM)	x .40 (I_B)	x .1578 loss	x 44 $/sq. ft. x 175,000 sq. ft. = $99,607
	.10 (RM)	x .60 (I_C)	x .1104 loss	
	.05 (RC)	x .40 (I_B)	x .2249 loss	x 66 $/sq. ft. x 175,000 sq. ft. = $105,971
	.05 (RC)	x .60 (I_C)	x .1559 loss	
	.50 (TU)	x .40 (I_B)	x .2472 loss	x 23 $/sq. ft. x 175,000 sq. ft. = $405,358
	.50 (TU)	x .60 (I_C)	x .1709 loss	
				= $786,653

Loss Summary*

Residential	$5,890,000
Education	280,000
Commercial	760,000
Industrial	790,000
	$7,720,000

*Values have been rounded to provide a more realistic estimate of accuracy.

III. OTHER POTENTIAL USES

A variety of other ways to use the land use and building stock data exist, including estimating (a) property losses, (b) homeless caseloads, and (c) casualties from future earthquakes. Each of these estimates requires progressively more assumptions about the earthquake and its effects, making them progressively more inaccurate. Because it was not the purpose of this project to evaluate these estimating techniques and because the potential inaccuracies in the assumptions necessary to make these estimate might detract from the other results of this project, the project staff and review committee decided not to calculate any of these estimates using actual building data, but rather to illustrate the property loss technique using a hypothetical sample census tract, as shown on the preceeding pages.

A. Estimating Property Losses

Estimating dollar property loss from a future earthquake requires five pieces of information:

- amount of building stock for each use (number of dwelling units, sq. ft. of commercial and industrial buildings);
- exposure of land use to ground shaking for the single earthquake in question;
- information on the construction type of building stock for each use;
- the replacement value of that building stock ($ value per dwelling unit and per sq. ft. of each construction type); and
- a table representing the damage curves for each building type occurring.

Some of the biggest assumptions in these estimates involve how the damage ranges described in PART A are translated into "exact" numbers to be used in calculating losses. With the fairly general building stock information available in this project it is more difficult to pick statistically accurate damage values. If damages were being estimated for something much smaller than a metropolitan area, such as for a city of 100,000, the curve values could be chosen to reflect the quality and degree of earthquake-resistive construction used in the community.

In addition, two major sources of damage values exist: a series of reports co-authored by Steinbrugge and Algermissen (1978; Rinehart and others, 1976) and a recent report published by the Applied Technology Council (ATC-13, draft, 1985). For purposes of an example of the type of calculation that could be performed using inventory data, a simplified set of Steinbrugge and Algermissen values have been used. Further information on the advantages and disadvantages of each set of curves is included in Appendix C. Finally, the values have been chosen to reflect the relationships between modified Mercalli intensity and San Francisco intensity described in Appendix D.

B. Estimating Homeload Caseloads

The residential building stock data, together with the damage matrices/curves, can be used to generate data on homeless caseloads, that is:

- o Number of units undamaged or damaged but repairable and livable
- o Number of units damaged and repairable but not livable on a temporary basis
- o Number of units damaged, not repairable and not livable

Assumptions of the cutoff points for these estimates vary. For example, a comparison of the percent damage associated with each of these three categories used by PEPPER, (H. J. Degenkolb Associates, 1985) Wiggins (oral communication, 1985), and Whitman (Whitman and others, 1974) follows:

	PEPPER	Wiggins	Whitman
Livable	0-50%	0-30%	0-20%
Temporarily not livable, repairable	50-80%	30-60%	20-65%
Lost units	80-100%	60-100%	65-100%

The actual number of homeless caseloads will depend, naturally, on more than physical damage because it relates to utility functioning, evacuation, access, and weather. In addition, the threshold of repairable will depend on the architectural and historic value of the building.

As a comparison of a couple of the options available, the two damage matrices for wood frame buildings (most housing units) are provided below in terms of these three categories.

TABLE C-2--

PEPPER AND WHITMAN DAMAGE MATRIX FOR WOOD FRAME

	MM Intensity				PEPPER	Wiggins	Whitman
% Damage	VI	VII	VIII	IX	Standards	Standards	Standards
0%	70	30	20	-			
0-1%	20	30	20	10			
1-5%	10	25	30	40	livable	livable	livable
5-20%	-	15	22	35			
20-50%	-	-	3	5		repairable	repairable
50-80%	-	-	2	5	repairable		
80-100%	-	-	3	5	lost	lost	lost

TABLE C-3--

ATC-13 DAMAGE MATRIX FOR WOOD FRAME

	MM Intensity							PEPPER	Wiggins	Whitman
% Damage	VI	VII	VIII	IX	X	XI	XII	Standards	Standards	Standards
0%	4	-	-	-	-	-	-			
0-1%	68	27	2	-	-	-	-			
1-10%	28	73	95	62	12	2	-	livable	livable	livable
10-30%	-	-	3	38	76	75	25			
30-60%	-	-	-	-	12	23	73		repairable	repairable
60-100%	-	-	-	-	-	-	2	repairable	lost	lost
100%	-	-	-	-	-	-	-	lost		

C. Estimating Casualties

The Applied Technology Council in a recent report (ATC-13, draft, 1985) contains a table and assumptions for generating casualties (injuries and deaths) from damage data. The basic table, as shown below, is for heavy construction (steel, masonry and concrete). As noted, for light construction (wood frame, light metal and mobile homes), the numbers should be divided by 10. The table is simple and is consistent with the matrix format of the ATC-13 data. Additional work would have to be done to convert all the Algermissen and Steinbrugge curves to matrix form if those curves are used in damage estimates.

TABLE C-4--

ATC-13 ASSUMPTIONS OF INJURIES AND DEATHS

(FOR HEAVY CONSTRUCTION)

[for light construction, divide these values by 10]

	Fraction Injured		Fraction
% Damage	Minor	Serious	Dead
0%	0	0	0
0-1%	3/100,000	1/250,000	1/1,000,000
1-10%	3/10,000	1/25,000	1/100,000
10-30%	3/1,000	1/2,500	1/10,000
30-60%	3/100	1/250	1/1,000
60-100%	3/10	1/25	1/100
100%	2/5	2/5	1/5

D. Other Benefits

There are several other possible uses of information on existing building stock. Those skilled in economic input-output modeling can use the data to project the impact of catastrophic earthquakes on the regional, state, and national economies. The data can be used as a first step in collecting information for local surveys of hazardous buildings, including unreinforced masonry, tilt-up concrete, inadequately reinforced concrete, and non-ductile concrete structures.

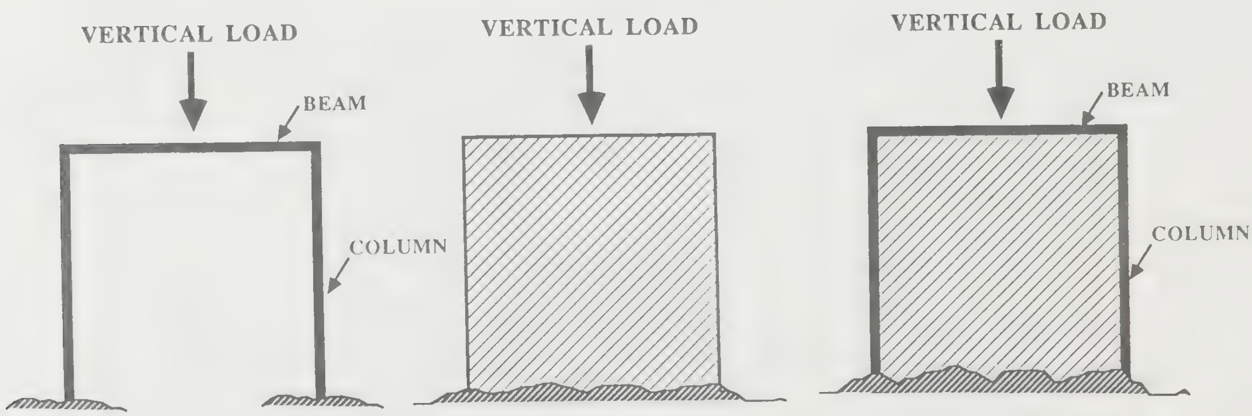
APPENDIX A--BUILDING COMPONENTS AND EARTHQUAKE FORCES

Before examining different types of buildings and their relative hazard, it is necessary to have a basic knowledge of building conponents and earthquake forces.

Earthquake forces result from the shaking of the ground on which the structure is supported. Although the ground vibrates both vertically and horizontally, it is customary to neglect the vertical components of the shaking since most structures have considerable excess strength in this direction due to safety factor requirements. The critical earthquake forces are horizontal forces, similar to wind except that they are based on the weight of the building rather than the "sail area" to the wind and are generally much larger. A major factor in earthquake-resistant design is that the forces are so large that they cannot be dealt with elastically (like vertical loads) but must rely on the ductility (or toughness) of the material and its connections to yield and still remain stable.

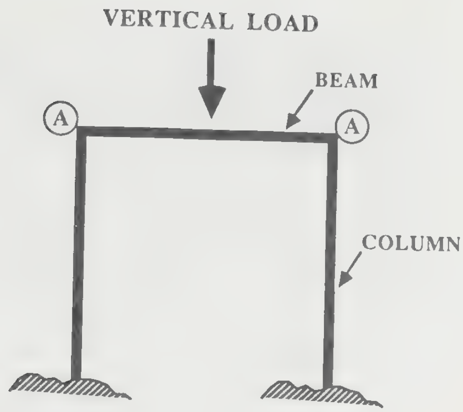
The theory and details of this process need not concern us here, except to realize the fact that actual earthquake forces are much greater than the Code design forces. Henry Degenkolb, a structural engineer specializing is earthquake-resistant design, notes that buildings designed to the full Code standards can still fall down in earthquakes.

There are two principal methods of carrying vertical loads. The first is a frame of beams and columns; the second is a wall. Because the wall bears the vertical loads, it is called a "bearing wall." If the area within the frame is filled in with a wall, this wall is called a "non-bearing wall." Note: if the walls or materials are within the plane (in the geometric sense) formed by the frame they generally are "infill walls" and can have an impact on structural response. Walls or partitions attached to that frame generally are non-structural "curtain walls." However, these distinctions can get vague.

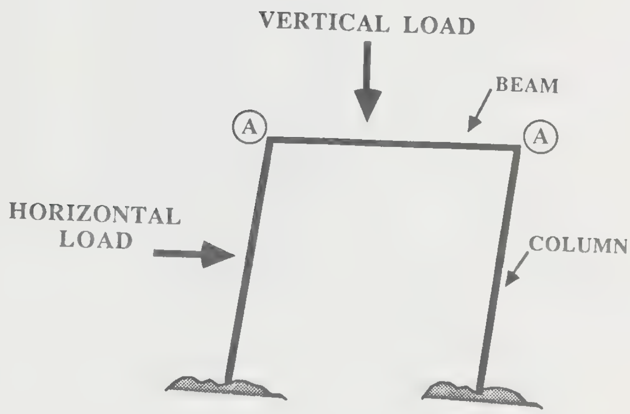


FRAME   BEARING WALL   FRAME WITH NON-BEARING WALL

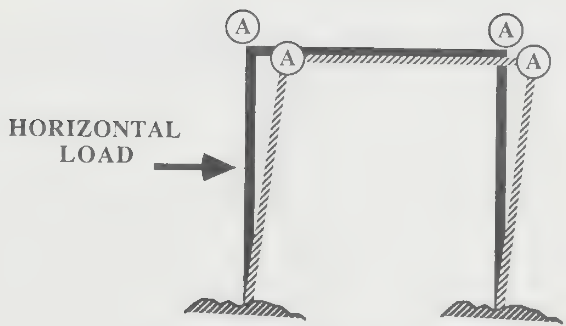
The major problem of resisting horizontal forces can be illustrated in this example. The system shown is stable for the vertical load on the beam even if there are hinges at the corners, shown as "A".



However, if we place a horizontal load on this frame, it will collapse, as shown here.

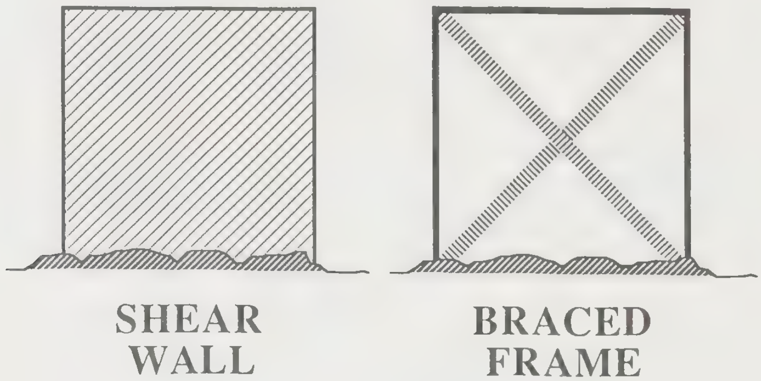


This need to resist the horizontal load can be solved in two basic ways. If we make the hinges rigid, as shown in this diagram, then the horizontal load is resisted by bending in the beams and columns. Rigid connections are the key component of so-called "moment-resisting frames."



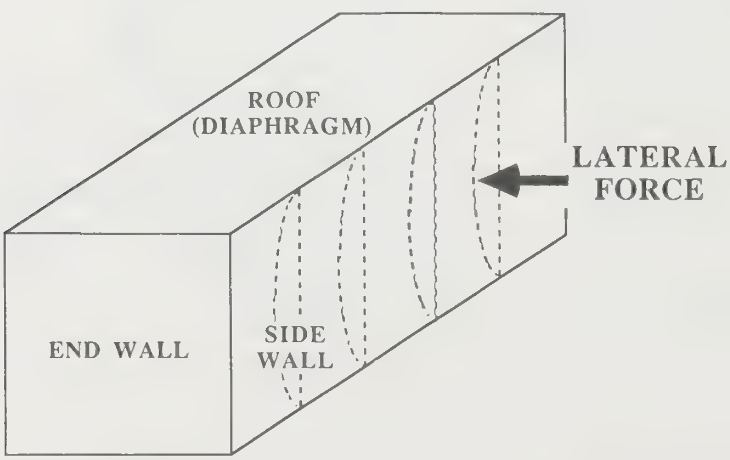
MOMENT-RESISTING FRAME

If we fill in the space between columns with a wall, as seen here, we also can resist the horizontal force. This wall is called a "shear wall". A similar system, shown here, with diagonal members instead of a wall, also can resist the horizontal forces. This system is called a "braced frame". Note: a bearing wall is usually a shear wall. A non-bearing wall may or may not be a shear wall. An infill wall may or may not be a shear wall, depending on whether the wall is tied into the frame suffiently along its sides to effectively transfer its shear strength to the framing system. A non-structural curtain wall is not a shear wall. The stiffness and connections of all walls must be considered when evaluating seismic-resisting elements.



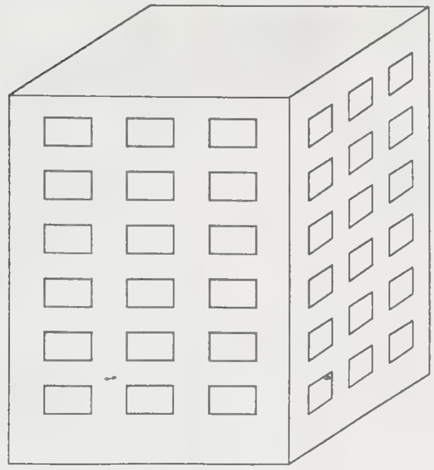
Using these basic concepts, we can look at typical buildings and analyze their horizontal load-resisting systems.

The simplest is the rectangular low building where all loads are taken by the walls and roof or floors. The walls, therefore, act as "shear walls."

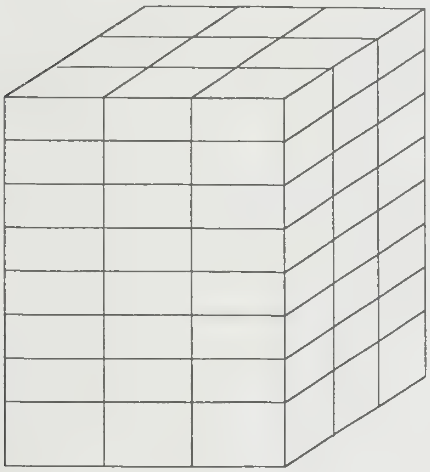


In larger structures, these concepts may be expanded into the all "shear wall" or "braced frame" structures shown here.

ALL SHEAR WALL OR BRACED FRAME

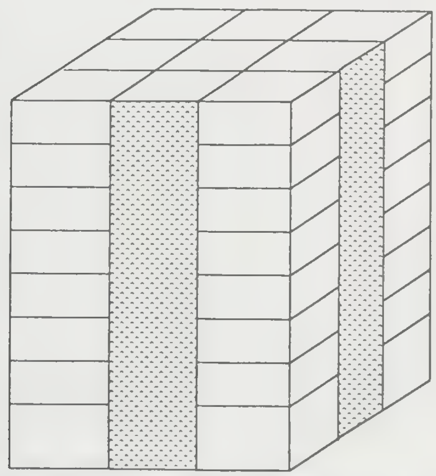


ALL MOMENT FRAME



The second type of framing, or the "moment-resisting frame," is shown here in a larger structure.
Columns and beams with rigid joints provide the lateral resistance and stability.

COMBINATION FRAME AND SHEAR WALL



The shear wall and moment-resisting frame may be combined into a single DUAL system as shown here.

Each type of system has its advantages and disadvantages, which vary with the size of building, occupancy, and location, as well as the local economy and construction practices.

APPENDIX B--TABLE--FLOOR AREA PER EMPLOYEE DATA

Employment Group	SIC Codes[1]		Square Footage per Employee[2]
Agriculture	01	Agricultural production--crops	758
	02	Agricultural production--livestock	0[3]
	07	Agricultural services	596[4]
	08	Forestry	0[3]
	09	Fishing, hunting, and trapping	545
Mining	10	Metal mining	29
	11	Anthracite mining	--[5]
	12	Bituminous coal and lignite mining	0[3]
	13	Oil and gas extraction	240
	14	Mining and quarrying of nonmetallic minerals, except fuels	325
Construction	15	Building construction--general contractors and operative builders	189
	16	Construction other than building construction--general contractors	196
	17	Construction-special trade contractors	319
Light Industrial	20	Manufacturing--food and like products	598
	21	Manufacturing--tobacco products	282
	22	Manufacturing--textile mill products	403
	23	Manufacturing--apparel and other finished products made from fabrics and similar materials	263
	25	Manufacturing--furniture and fixtures	628
	27	Manufacturing--printing, publishing, and allied industries	363
	31	Manufacturing--leather and leather products	345
	36	Manufacturing--electrical and electronic machinery, equipment, and supplies	255
	38	Manufacturing--measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks	253
	39	Manufacturing--miscellaneous manufacturing industries	426

Heavy Industrial	24	Manufacturing--lumber and wood products, except furniture	796
	26	Manufacturing--paper and allied products	649
	28	Manufacturing--chemicals and allied products	649
	29	Manufacturing--petroleum refining and related industries	394
	30	Manufacturing--rubber and miscellaneous plastics products	604
	32	Manufacturing--stone, clay, glass, and concrete products	545
	33	Manufacturing--primary metal industries	352
	34	Manufacturing--fabricated metal products, except machinery and transportation equipment	476
	35	Manufacturing--machinery, except electrical	418
	37	Manufacturing--transportation equipment	313[6]
Rail	40	Railroad transportation	187[7]
Transit	41	Local and suburban transit and interurban highway passenger transportation	280
Road	42	Motor freight transportation and warehousing	3,162
Postal	43	U.S. Postal Service	--[8]
Water	44	Water transportation	139[7]
Air	45	Transportation by air	809
Pipe	46	Pipe lines, except natural gas	247[9]
Transportation Services	47	Transportation services	780
Communication	48	Communication	177
Utilities	49	Electrical, gas, and sanitary services	247
Wholesale Trade	50	Wholesale trade--durable goods	682
	51	Wholesale trade--nondurable goods	682[10]

Most Retail and Services	52	Retail--building materials, hardware, garden supply, and mobile home dealers	982
	53	Retail--general merchandise stores	271
	54	Retail--food stores	509
	55	Retail--automotive dealers and gasoline service stations	502
	56	Retail--apparel and accessory stores	532
	57	Retail--furniture, home furnishings, and equipment stores	878
	58	Retail--eating and drinking places	270
	59	Retail--miscellaneous retail	444
	60	FIRE[11]--banking	155
	61	FIRE--credit agencies other than banks	214
	62	FIRE--security and commodity brokers, dealers, exchanges, and services	176
	63	FIRE--insurance	149
	64	FIRE--insurance agents, brokers, and insurance services	149
	65	FIRE--real estate	390
	66	FIRE--combination of real estate, insurance, loans, and law offices	187
	67	FIRE--holding and investment companies	156
	72	Services--personal services	304
	73	Services--business services	275
	75	Services--automotive repair, services, and garages	1,422
	76	Services--miscellaneous repair services	270
	78	Services--motion pictures	777
	81	Services--legal services	211
	83	Services--social services	339[12]
	84	Services--museums, art galleries, botanical and zoological gardens	2,000
	86	Services--membership organizations	860
	88	Services--private households	0[3]
	89	Services--miscellaneous services	312
Hotels	70	Hotels, rooming houses, camps, and other lodging places	837
Amusement and Recreation	79	Amusement and recreation services, except motion pictures	871
Health Services	80	Health services	210
Education	82	Educational services	697

Government	91	Executive, legislative, and general government, except finance	194
	92	Justice, public order, and safety	183
	93	Public finance, taxation, and monetary policy	393
	94	Administration of human resources programs	257[13]
	95	Administration of environmental quality and housing programs	257[13]
	96	Administration of economic programs	257[13]
	97	National security and international affairs	257[13]
Other	99	Nonclassifiable establishments	--[5]

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1 SIC Codes are Standard Industrial Classification Codes.

2 From Federal Highway Administration (1970) unless noted.

3 No FHA (1970) data. No significant building stock assumed.

4 FHA (1970) data for this SIC Code of 2,987 square feet per employee was based on 14 companies nationwide. ATC-13 (1985) assumed 540 square feet per employee by relating this classification to food and drug production. However, by examining county-level data for the more detailed 4-digit SIC Codes, one determines that the employment is dominated in the San Francisco Bay Area by a mixture of veternary sevices and landscape services. If one averages the FHA data for health services (210 sq. ft./employee) and for retail trade--building materials (982 sq. ft./employee), a more reasonable number results and is substituted for the FHA data here.

5 No Bay Area employment and no FHA (1970) data.

6 FHA (1970) lists separate square footages for SIC Code 37 of 313 and SIC Code 19 (ordnance and accessories) of 206. Since 1970, SIC Code 19 has been combined with SIC Code 37. Data for SIC Code 37 is included here.

7 No Bay Area employment.

8 No FHA (1970) data. Employment combined with government (SIC Code 91).

9 FHA (1970) data for this SIC Code of 8,050 square feet per employee was based on only one company nationwide. Data for SIC Code 49 (electric, gas, and sanitary services) of 247 square feet per employee was substituted for the FHA data here. However, there is no employment for this SIC Code in the Bay Area.

10 No FHA (1970) data. FHA data for SIC Code 50 included here.

11 FIRE stands for Finance, Insurance, and Real Estate.

12 No FHA (1970) data. The average of the values for similar SIC Codes (72, 73, 80, 81 and 82) or 339 square feet per employee was used here.

13 No FHA (1970) data. FHA data for SIC Codes 91, 92, and 93 were averaged and included here. Note that SIC Code 97 only has 11 employees in the Bay Area.

APPENDIX C--CHOICE OF DAMAGE CURVES OR MATRICES

At the present time, several techniques have been developed to describe the relationship between building type and intensity in terms of expected damage. The principal one is based on several reports prepared by Algermissen and Steinbrugge. (See Rinehart and others, 1976, and Algermissen and Steinbrugge, 1978, for example.) The reports can be used to produce a set of damage curves, as shown in Figure 1-A using the descriptions of building types in Table 1-A. These curves were generalized to fit a set of simplified building classes by H.J. Degenkolb Associates for use by William Spangle and Associates for their PEPPER project covering the City of Los Angeles. Similar curves have been used in PART A of this report. A second technique is based on consensus opinion of a set of "experts" and is becoming available the Applied Technology Council as its ATC-13 report. ATC-13 contains a set of damage matrices, similar to that shown in Table 3-A for wood frame buildings. The building classes for which these matrices are being developed are listed in Table 2-A. Finally, the relationships between the ABAG and ATC-13 building classes are shown in Table 3-B. Use of either set of curves/matrices with ABAG building stock information would be acceptable; neither set is optimal. The biggest problem is the scarcity of damage data. The advantages and disadvantages of the Steinbrugge/PEPPER-type curves, together with those for the ATC-13 matrices are listed below. FEMA currently has a contract with the National Research Council to study alternative methods for producing loss estimates.

Steinbrugge/PEPPER Curves

PROS -- Commonly used in this field.
-- In curve form to make damage estimates relatively simple.

CONS -- Need to extrapolate damage for MM intensities above IX. (The occurrence of San Francisco intensity A on the ABAG maps is so limited that this extrapolation process is not critical in any loss estimate.)
-- Not commonly in matrix form so homeless caseload assignments may be more difficult (PEPPER used three matrices to perform homeless caseload assignments.)
-- Unclear definition of building classes.

ATC-13 Matrices

PROS -- Based on consensus opinion so theoretically based on a mix of "best" data available.
-- In matrix form to make homeless caseload assignments simpler (see Appendix B). Assigned damages for MM intensities above IX.

CONS -- Switching to curve form will require some effort.
-- Numerous matrices for concrete and steel building would be difficult to simplify into a small set suitable for use with the ABAG data.
-- Because of the way the building classes are defined, the same building can fall in two, or perhaps even three classes, depending on whether priority is given the framing system material, the shear wall material, or the long roof span.
-- Not accepted by research community.

TABLE 1-A--STEINBRUGGE BUILDING CLASSES

Notation used for loss curves (Figure 1-A)	Brief description of subclasses of five broad building classes
1A	Wood-frame and frame-stucco dwellings.
1B	Wood-frame and frame-stucco buildings not qualifying under 1A (usually large-area nonhabitational units); (not considered in this study).
2A	One story, all metal; floor area less than 20,000 feet^2.
2B	All metal buildings not considered under 2A.
3LA	Steel frame, superior damage-control features; less than four stories.
3LB	Steel frame; ordinary damage-control features; less than four stories.
3LC	Steel frame; intermediate damage-control features (between 3LA and 3LB); less than four stories.
3LD	Floors and roofs not concrete; less than four stories.
3HA, 3HB, 3HC, 3HD	Descriptions are the same as for 3LA, 3LB, 3LC, and 3LD except that buildings have four or more stories.
4LA	Reinforced concrete; superior damage-control features; less than four stories.
4LB	Reinforced concrete; ordinary damage-control features; less than four stories.
4LC	Reinforced concrete; intermediate damage-control features (between 4LA and 4LB); less than four stories.
4LD	Precast reinforced concrete, lift slab, less than four stories.
4LE	Floors and roofs not concrete, less than four stories.
4HA, 4HB, 4HC, 4HD, 4HE	Descriptions are the same as for 4LA, 4LB, 4LC, 4LD, and 4LE except that buildings have four or more stories.
5A	Dwellings, not over two stories in height, constructed of (a) poured-in-place reinforced concrete, with roofs and second floors of wood frame or (b) adequately reinforced brick or hollow-concrete-block masonry, with roofs and floors of wood (not considered in this study).
5B	One-story buildings having superior earthquake damage-control features, including exterior walls of (a) poured-in-place reinforced concrete, and (or) (b) precast reinforced concrete, and (or) (c) reinforced brick masonry or reinforced-concrete brick masonry, and (or) (d) reinforced hollow-concrete-block masonry. Roofs and supported floors are of wood or metal-diaphragm assemblies. Interior bearing walls are of wood frame or any one, or a combination, of the aforementioned wall materials.
5C	One-story buildings having construction materials listed for Class 5B, but with ordinary earthquake damage-control features.
5D	Buildings having reinforced concrete load-bearing walls and floors and roofs of wood, but not qualifying for Class 4E; and buildings of any height having Class 5B materials of construction, including wall reinforcement; also included are buildings with roofs and supported floors of reinforced concrete (precast or otherwise) not qualifying for Class 4.
5E	Buildings having unreinforced solid-unit masonry of unreinforced brick, unreinforced concrete brick, unreinforced stone, or unreinforced concrete, where the loads are carried in whole or in part by the walls and partitions. Interior partitions may be wood frame or any of the aforementioned materials. Roofs and floors may be of any material. Not qualifying are buildings having nonreinforced load walls of hollow tile or other hollow-unit-masonry, adobe, or cavity construction.
5F	Buildings having load-carrying walls of hollow tile or other hollow-unit-masonry construction, adobe, and cavity-wall construction, and any building not covered by any other class (not considered in this study).

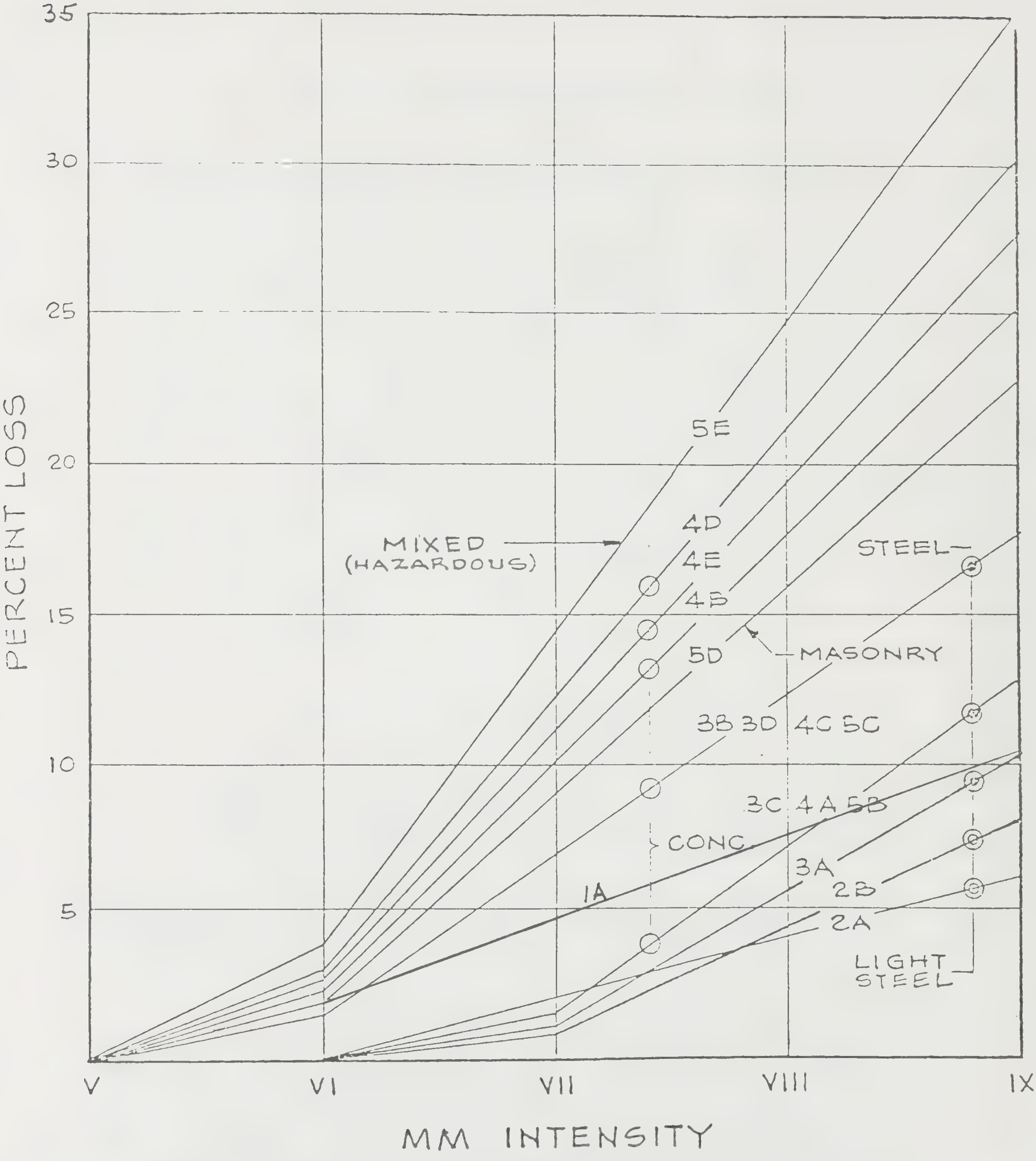


FIGURE 1-A--STEINBRUGGE DAMAGE CURVES

TABLE 2-A
ATC-13 BUILDING CLASSES
(Damage Probability Matrix Number Follows Each Class)

Wood frame -- low-rise (1)
Light metal -- low (2)
Mobile homes -- low (23)
Unreinforced masonry, bearing wall -- low (75)/mid(76)/high(77)
Unreinforced masonry, with load bearing frame -- low(78)/mid(79)/high(80)
Reinforced masonry shear wall, without moment resisting frame -- low(9)/mid(10)/high(11)
Reinforced masonry shear wall, with moment resisting frame -- low (84)/mid(85)/high(86)
Reinforced concrete shear wall, without moment resisting frame -- low(6)/mid(7)/high(8)
Reinforced concrete shear wall, with moment resisting frame -- low(3)/mid(4)/high(5)
Moment resisting non-ductile concrete frame -- low(87)/mid(88)/high(89)
Moment resisting ductile concrete frame -- low(18)/mid(19)/high(20)
Tilt-up concrete - low(21)
Pre-cast concrete, other than tilt-up -- low(81)/mid(82)/high(83)
Braced steel frame -- low(12)/mid(13)/high(14)
Moment resisting steel frame, perimeter frame -- low(15)/mid(16)/high(17)
Moment resisting steel frame, distributed frame -- low(72)/mid(73)/high(74)
Long-span (91)

Note: Missing numbers = (22); (24)-(71); (90)

TABLE 3-A
SAMPLE ATC-13 DAMAGE MATRIX FOR WOOD FRAME BUILDINGS

	MM Intensity						
% Damage	VI	VII	VIII	IX	X	XI	XII
0%	4	-	-	-	-	-	-
0-1%	68	27	2	-	-	-	-
1-10%	28	73	95	62	12	2	-
10-30%	-	-	3	38	76	75	25
30-60%	-	-	-	-	12	23	73
60-100%	-	-	-	-	-	-	2
100%	-	-	-	-	-	-	-

TABLE 4-A
RELATIONSHIPS BETWEEN ABAG AND ATC-13 BUILDING CLASSES

ABAG Building Classes*		ATC-13 Building Classes**
Light Materials		
Wood frame	Low*	(1)
	Mid*	(1)
Light metal	Low	(2)
Mobile home unit	Low	(23)
Masonry		
Unknown reinforcing	Low	(19)+(75)
	Mid	(10)+(76)
Reinforced	Low	(9)
	Mid	(10)
	High	(11)
Seismically suspicious	Low*	(75)
	Mid*	(76)
Concrete and Steel		
Unknown composition	Low*	(3)+(6)+(12)+(15)+(18)+(72)+(78)+(81)+(84)+(87)
	Mid*	(4),+(7)+(13)+(16)+(19)+(73)+(79)+(82)+(85)+(88)
Steel frame	Low*	(12)+(15)+(72)
	Mid*	(13)+(16)+(73)
	High*	(14)+(17)+(74)
Concrete	Low*	(6)+(18)+(81)+(87)
	Mid*	(7)+(19)+(82)+(88)
	High*	(8)+(20)+(83)+(89)
Tilt-up concrete	Low*	(21)

* Some further refinement based on decade of construction may be feasible for some buildings.

**Long-span (91) was not assigned. High-rise unreinforced masonry bearing wall (77) does not occur. In addition, types assigned by material of walls that had frames were eliminated from consideration except as parts of the general concrete and steel category (3)(78)(84)/(4)(79)(85)/(5)(80)(86).

APPENDIX D--DAMAGE CURVES FOR SAN FRANCISCO INTENSITIES

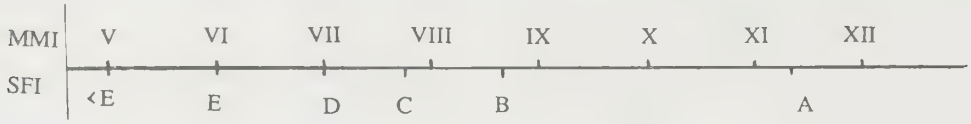
As stated in PART C, Section I, ABAG's intesnity maps are in San Francisco intensity (SFI), not modified Mercalli intensity (MMI) so the damage curves (available in MMI) will need to be converted to SFI. The following table shows the approximate relationships between the two scales.

San Francisco scale	Modified Mercalli scale
A- Very Violent	XII
	XI
B- Violent	X
	IX
	VIII
C- Very Strong	
D- Strong	VII
	VI
E- Weak	

Two conversion options are possible. The simplest technique is directly converting the MMI scale to SFI, as shown below:

Modified Mercalli Intensity	Estimated San Francisco Intensity
V	<E
VI	E
VII	D
VIII	C
IX	
X	B
XI	
XII	A

A second technique would be to assign the San Francisco scale directly to the horizontal scale on the intensity curves. Since the damage data points for the MMI Roman numerals are at the bottom of the full MMI range, one can extract similar data points corresponding to the SFI letters, as shown below.



This "refinement" would mean chosing a point on a curve or matrix for intensity C that is 3/4 of the distance between VII and VIII, chosing a point for intensity B that is 2/3 of the distance between VIII and IX, and chosing a point for intensity A that is 1/3 of the distance betwen XI and XII.

APPENDIX E -- OCCURRENCE OF SEISMICALLY SUSPICIOUS MASONRY BUILDINGS IN THE SAN FRANCISCO BAY AREA

	CITY	# BUILDINGS
ALAMEDA CO.	Alameda	~68
	Albany	~37
	Berkeley	~93
	Dublin	< 5
	Emeryville	0-20
	Fremont	~20
	Hayward	~60
	Livermore	~25
	Newark	< 5
	Oakland	500-600
	Piedmont	~ 5
	Pleasanton	~10
	San Leandro	21-26
	Union City	< 5
	Unincorporated	0-20
	TOTAL	830-980
CONTRA COSTA CO.	Antioch	15-20
	Brentwood	< 5
	Clayton	< 5
	Concord	< 5
	Danville	< 5
	El Cerrito	5-50
	Hercules	< 5
	Lafayette	< 5
	Martinez	54
	Moraga	< 5
	Pinole	4-6
	Pittsburg	5-7
	Pleasant Hill	~12
	Richmond	10-20
	San Pablo	< 5
	San Ramon	< 5
	Walnut Creek	5-15
	Unincorporated	<11
	TOTAL	170-270
MARIN CO.	Belvedere	< 5
	Corte Madera	< 5
	Fairfax	< 5
	Larkspur	< 5
	Mill Valley	10-100
	Novato	4+
	Ross	< 5
	San Anselmo	20-30
	San Rafael	50-100
	Sausalito	< 5
	Tiburon	< 5
	Unincorporated	< 5
	TOTAL	90-240
NAPA CO.	Calistoga	6-7
	Napa	15-25
	St. Helena	10-20
	Yountville	10-20
	Unincorporated	5-20
	TOTAL	50-90
SAN FRANCISCO	TOTAL	2058

	CITY	# BUILDINGS
SAN MATEO CO.	Atherton	< 5
	Belmont	< 5
	Brisbane	< 5
	Burlingame	40-50
	Colma	< 5
	Daly City	< 5
	East Palo Alto	< 5
	Foster City	< 5
	Half Moon Bay	< 5
	Hillsborough	< 5
	Menlo Park	5-20
	Millbrae	< 5
	Pacifica	< 5
	Portola Valley	< 5
	Redwood City	~40
	San Bruno	< 5
	San Carlos	~90
	San Mateo	~ 8
	So. San Francisco	~10-15
	Woodside	< 5
	Unincorporated	< 5
	TOTAL (w/o rehab.)	~235
SANTA CLARA CO.	Campbell	10-15
	Cupertino	< 5
	Gilroy	~20
	Los Altos	~30
	Los Altos Hills	< 5
	Los Gatos	50-60
	Milpitas	< 5
	Monte Sereno	< 5
	Morgan Hill	< 5
	Mountain View	60-75
	Palo Alto	50
	San Jose	~200
	Santa Clara	~20
	Saratoga	~ 7
	Sunnyvale	~40
	Unincorporated	~30-60
	TOTAL (w/o rehab.)	~400
SOLANO CO.	Benecia	~ 8
	Dixon	16-20
	Fairfield	< 5
	Rio Vista	10-25
	Suisun City	5-10
	Vacaville	5-10
	Vallejo	~44
	Unincorporated	< 5
	TOTAL (w/o rehab.)	~105
SONOMA CO.	Cloverdale	< 5
	Cotati	< 5
	Healdsburg	< 5
	Petaluma	100-125
	Rohnert Park	< 5
	Santa Rosa	~500
	Sebastopol	39
	Sonoma	42
	Unincorporated	0-20
	TOTAL (w/o rehab.)	~555

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Building Stock and Earthquake Losses--The San Francisco Bay Area Example

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